



## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification <sup>6</sup> :		A1	(11) International Publication Number:	WO 99/14220
C07F 7/08, 7/18, 7/02, 9/02, 9/22, C07D 219/00, 221/06, 221/12, 327/00, 335/09			(43) International Publication Date:	25 March 1999 (25.03.99)
(21) International Application Number:		PCT/US98/15734	(81) Designated States:	AU, CA, CN, JP, KR, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).
(22) International Filing Date:		12 August 1998 (12.08.98)		
(30) Priority Data: 08/927,381 12 September 1997 (12.09.97) US			Published	<i>With international search report. Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i>
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(54) Title: NOVEL COMPOUNDS FOR GENERATING CHEMILUMINESCENCE WITH A PEROXIDASE

## (57) Abstract

Novel compounds comprising a C-C double bond substituted at one carbon with two oxygen or sulfur atom-containing groups are disclosed. The compounds are useful in methods and compositions for generating chemiluminescence by reaction with a peroxidase enzyme and a peroxide. The chemiluminescence thus produced can be used as a detectable signal in assays for peroxidase enzymes and in assays employing enzyme-labeled specific binding pairs.

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NOVEL COMPOUNDS FOR GENERATING CHEMILUMINESCENCE WITH  
A PEROXIDASE

FIELD OF THE INVENTION

The present invention relates to chemiluminescent compositions which react with a peroxidase and a peroxide to generate chemiluminescence. In particular, the present invention relates to compositions containing novel electron-rich alkenes which react with a peroxidase and a peroxide to produce an excited state carbonyl compound. The invention further relates to assay methods for detecting a peroxidase and for detecting peroxidase-labeled specific binding partners in immunoassays, nucleic acid probe assays and the like.

BACKGROUND OF THE INVENTION

Peroxidase enzymes such as horseradish peroxidase (HRP) are frequently used as markers or labels in enzyme-linked assays for biological molecules and other analytes of interest such as drugs, hormones, steroids and cancer markers. Chemiluminescent detection of these enzymes offers a safe, convenient and sensitive means to provide a quantitative measure of the amount of enzyme in a sample or of the amount of an enzyme-labeled analyte or labeled specific binding partner for an analyte. Other chemiluminescent reaction schemes have been developed to quantitate the level of particular peroxidase enzymes.

a. Chemiluminescent Peroxidase Substrates.

Amino-substituted cyclic acylhydrazides such as the well-known luminol and isoluminol react with  $H_2O_2$  and a peroxidase catalyst (such as horseradish peroxidase, HRP) under basic conditions with emission of light. This reaction has been used as the basis for analytical methods for the detection of

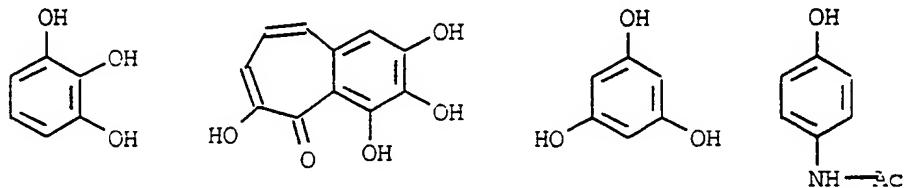
H<sub>2</sub>O<sub>2</sub> and for the peroxidase. Heterocyclic analogs of luminol such as (8-amino-5-chloro- 7-phenylpyrido[3,4-d-pyridazine-1,4(2H,3H)dione (M. Ii, et al., Biochem. Biophys. Res. Comm., 193(2), 540-5 (1993)); pyridazinoquinoxalinones (U.S. Patent No. 5,324,835) and 1,3-disubstituted pyrazolo[4',3':5',6']pyrido-[2,3-d]-pyrazinediones (Y. Tominaga, et al., Tetrahedron Lett., 36, 8641-4 (1995)) are known to react with a peroxidase and peroxide to produce chemiluminescence. Other hydrazide compounds which are 10 chemiluminescent when oxidized by a peroxidase and a peroxide are hydroxy-substituted phthalhydrazides (U.S. Patent No. 5,552,298).

Applicant's U.S. Patent Nos. 5,491,072, 5,523,212 and 5,593,845 disclose chemiluminescent N-alkylacridan-carboxylic acid esters, thioesters and sulfonimides which produce light upon reaction with a peroxide and a peroxidase for use in detecting peroxidases and in assays. A PCT application (WO 94/02486) describes the chemiluminescent reaction of spiroacridan compounds with hydrogen peroxide. The reaction 20 is enhanced by the addition of horseradish peroxidase.

Various compounds of biological origin, collectively termed luciferins, are oxidized by a peroxidase (summarized in L.J Kricka and G.H.G. Thorpe, in Luminescence Immunoassay and Molecular Applications, K. Van Dyke and R. Van Dyke, eds., CRC Press, Boca Raton, 1990, pp. 77-98). In some instances, hydrogen peroxide is not utilized in which case the enzyme is functioning as an oxidase.

Certain phenol compounds produce chemiluminescence on oxidation with a peroxidase. As examples, pyrogallol B-1 and 30 purpurogallin B-2 are cited in Kricka and Thorpe, ibid. as well as the coumarin-type compounds coumarin, umbelliferone

and esculin (D. Slawinska, J. Slowinski, J. Biolumin. Chemilumin., 4, 226-30 (1989)); phloroglucinol B-3 (M. Halmann, et al., Photochem. Photobiol., 30, 165-7 (1979)); and acetaminophen B-4 (K. Schmitt, G. Cilento, Photochem. Photobiol., 51, 719-23 (1990)).



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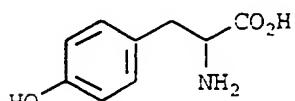
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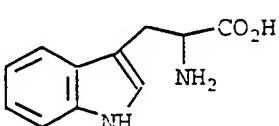
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Other miscellaneous compounds reported to produce weak chemiluminescence in the presence of oxygen or peroxide and a peroxidase are a synthetic Schiff base-containing polymer ((R. Zoulik, et al., Coll. Czech. Chem. Commun., 60, 95-103 (1995)); indole-3-acetic acid in the presence of xanthene dyes with or without hydrogen peroxide (S. Krylov, A. Chebotareva, FEBS, 324(1), 6-8 (1993); tyrosine, tryptophan and chlorpromazine (M. Nakano, J. Biolumin. Chemilumin. 4, 15 231-40 (1989)) and MCLA B-3 M. (Mitani, et al., J. Biolumin. Chemilumin. 9, 355-61 (1994)) which have the respective structures B-5-B-8 as shown below.

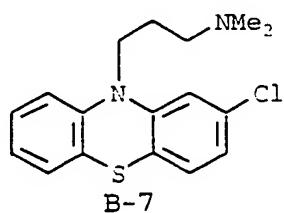
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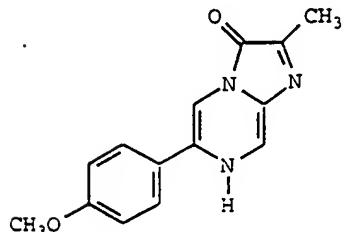


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B-8

None of the foregoing references disclose the chemiluminescent oxidation of the presently disclosed compounds by a peroxidase

5       **b. Reaction of Enols with HRP.** A series of papers describe the peroxidase-catalyzed air oxidation of enolizable aldehydes (H. Gallardo, et al., Biochim. Biophys. Acta, 789, 57-62 (1984); W.J. Baader, et al., Biochem. Ed., 14(4), 190-2 (1986); I. Nantes, et al., Photochem. Photobiol., 63(6), 702-10 8 (1996)). The reactive substrate is thought to be the small quantity of the enol form in equilibrium with the aldehyde. The reaction of the aldehyde is catalyzed by enol phosphates, but the enol phosphate itself is not consumed. The reference teaches that the enol phosphate does not react with a 15 peroxidase to produce chemiluminescence. Energy transfer to fluorescent energy acceptors increased light emission (M.T. Grijalba, et al., Photochem. Photobiol., 63(6), 697-701 (1996)). Aldehydes masked as enol silyl ethers (Baader, *ibid*) or enol acetates were used in coupled assays in which the 20 enol was unmasked in a first step to generate an enol *in situ* which subsequently reacted with a peroxidase to generate chemiluminescence (A. Campa, et al., Photochem. Photobiol., 63(6), 742-5 (1996)).

25       **c. Peroxidase Enhancers.** Numerous enhancers have been employed in order to increase the quantity and duration of chemiluminescence from the reaction of a peroxidases with known chemiluminescent substrates including the aforementioned luminol and the acridancarboxylic acid derivatives. These include benzothiazole derivatives such as 30 D-luciferin, various phenolic compounds such as p-iodophenol, p-phenylphenol, naphthols and aromatic amines as listed in G.

Thorpe, L. Kricka, in *Bioluminescence and Chemiluminescence New Perspectives*, J. Scholmerich, et al, Eds., pp. 199-208 (1987). Other compounds which function as enhancers of the chemiluminescent oxidation of amino-substituted cyclic acylhydrazides by a peroxidase include 4-(4-hydroxyphenyl)-thiazole (M. Ii, *ibid.*), a group of compounds disclosed in U.S. Patent 5,171,668, 2-hydroxy-9-fluorenone, and a group of hydroxy-substituted benzoxazole derivatives as disclosed in U. S. Patent 5,206,149 and certain phenylboronic acid compounds as described in U. S. Patent 5,629,168. None of the foregoing references disclose the chemiluminescent oxidation of the present compounds by a peroxidase alone or with the use of enhancers.

d. Enhancement of Chemiluminescent Peroxidase Reactions by Surfactants. Enhancement of the chemiluminescence produced in peroxidase-catalyzed reactions using polymeric and monomeric surfactants is known in the art. Enhancement can occur by affecting the outcome of one or more steps e.g. by increasing the fluorescence quantum yield of the emitter, by increasing the percentage of product molecules produced in the excited state, by increasing the fraction of molecules undergoing the chemiluminescent reaction through inhibition of competing side reactions or by promoting the action of an enzyme catalyst. No clear or consistent pattern exists concerning the effect of polymeric and monomeric surfactants on chemiluminescent reactions. It is impossible to predict which surfactant compounds, if any, may enhance the chemiluminescence from a particular process and can only be determined by substantial experimentation.

The cationic polymeric surfactant poly-N-ethyl-4-vinyl-pyridinium bromide completely inhibited the chemiluminescent

reaction of luminol by a negatively charged insulin-peroxidase conjugate and diminished chemiluminescence to a lesser extent when the native enzyme was used (S.B. Vlasenko, et al., *J. Biolumin. Chemilumin. A*, 164-176 (1989)).

5       A published Japanese Patent Application No. JP 06,242,111 and a paper (R. Iwata, et al., *Anal. Biochem.*, 231, 170-4 (1995)) disclose the use of nonionic surfactant and skim milk in the chemiluminescent peroxidation of luminol to lower background emission or enhance signal/noise.

10      None of the foregoing references disclose the chemiluminescent oxidation of the present compounds by a peroxidase or chemiluminescence enhancement with surfactants.

d. Assays using HRP. The enzyme horseradish peroxidase has found widespread use in enzyme immunoassays and DNA hybridization assays with chemiluminescent detection using luminol or isoluminol as substrate. Commercially available kits using HRP conjugates and enhanced luminol chemiluminescent detection are available. Chemiluminescent peroxidase assays are also disclosed in the aforementioned U.S. Patents 5,491,072, 5,523,212 and 5,593,845. No references disclose the chemiluminescent peroxidase assays using the present compounds as the substrates.

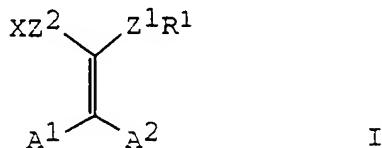
#### SUMMARY OF THE INVENTION

25      It is an object of the present invention to provide compositions containing compounds which react with a peroxidase and a peroxide to provide chemiluminescence.

It is another object of the present invention to provide compositions containing compounds which react with a peroxidase and a peroxide to provide chemiluminescence for detection of the peroxidase.

It is also an object of the present invention to provide compositions containing compounds of formula I containing a carbon-carbon double bond substituted at one terminus of the double bond with two atoms selected from oxygen or sulfur 5 each attached to another group X or R<sup>1</sup> and substituted at the other terminus of the double bond with two groups A<sup>1</sup> and A<sup>2</sup> selected so that an excited state product A<sup>1</sup>A<sup>2</sup>C=O\* results upon reaction of I with a peroxidase and a peroxide.

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It is a further object of the present invention to provide compositions containing compounds of formula I wherein A<sup>1</sup> and A<sup>2</sup> together with the carbon atom to which they are bonded form a heterocyclic or carbocyclic ring. In particular the ring can be a nitrogen, sulfur or oxygen-containing heterocyclic ring group.

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It is a further object of the present invention to provide compositions containing compounds of formula I wherein when Z<sup>2</sup> is O the group attached to the oxygen atom is part of an alkoxy group, an aryloxy group, an aralkyloxy group, a phosphate mono-, di- or triester group, a carboxyl ester group, a sulfate group, a sugar group or a silyl ether group and when Z<sup>2</sup> is S the group attached to the sulfur atom is part 25 of the equivalent thio groups.

It is a further object of the present invention to provide methods for generating chemiluminescence upon reaction with a peroxidase and a peroxide employing the present compositions.

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Still further, it is an object of the present invention to provide a method and compositions for enhancing the chemiluminescence produced on reaction of compounds of the

present invention with a peroxidase.

It is yet another object of the present invention to provide chemiluminescent compositions and methods for use in detecting peroxidases and conjugates in immunoassays, nucleic acid probe assays, western blot assays, Southern blot assays and other assays by generally known methods which employ enzyme labels for detection of analytes. The assays are thus useful for detecting analytes in such assays by detecting the peroxidase or conjugate and relating the chemiluminescence produced thereby to the presence or amount of the analyte.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a graph relating the amount of HRP to the chemiluminescence intensity at 15 min emitted by 100  $\mu\text{L}$  of a reagent described in Example 20 containing acridan phosphate 5 triggered at room temperature. Chemiluminescence emission was initiated by addition of 10  $\mu\text{L}$  of solutions of HRP containing between  $1.4 \times 10^{-15}$  and  $1.4 \times 10^{-19}$  moles of enzyme to 100  $\mu\text{L}$  of the reagent comprising 0.055 M tris buffer, pH 8.6, 0.25 mM urea peroxide, 0.05 mM p-phenylphenol, 0.5 mM EDTA, 0.0125% Tween 20 and  $3.3 \times 10^{-4}$  M acridan 5 in the wells of a black microplate. The term S-B refers to the chemiluminescence signal (S) in Relative Light Units (RLU) in the presence of HRP corrected for background chemiluminescence (B) in the absence of HRP.

Figure 2 is a graph relating the amount of HRP to the chemiluminescence intensity at 15 min emitted by 100  $\mu\text{L}$  of a reagent described in Example 21 containing acridan phosphate 13 triggered at room temperature. Chemiluminescence emission was initiated by addition of 10  $\mu\text{L}$  of solutions of HRP containing between  $1.4 \times 10^{-15}$  and  $1.4 \times 10^{-19}$  moles of enzyme

to 100  $\mu$ L of a reagent comprising 0.055 M tris buffer, pH 8.6, 0.25 mM urea peroxide, 0.05 mM p-phenylphenol, 0.5 mM EDTA, 0.0125% Tween 20 and  $3.3 \times 10^{-4}$  M acridan 13 in a black microplate.

5       Figure 3 is a graph showing the time profile of chemiluminescence resulting from reaction of  $1.4 \times 10^{-15}$  moles of HRP at 25 °C with 100  $\mu$ L of the reagent containing acridan 5 described in Example 20.

10      Figure 4 is a graph relating the amount of HRP to the maximum chemiluminescence intensity at 2 min emitted by 100  $\mu$ L of a reagent containing acridan 37 triggered at room temperature. Chemiluminescence emission was initiated by addition of 10  $\mu$ L of solutions of HRP containing between  $1.4 \times 10^{-14}$  to  $1.4 \times 10^{-19}$  moles to 100  $\mu$ L of reagent composition 15 comprising 0.01 M tris buffer, pH 8.0, 0.5 mM urea peroxide, 0.1 mM p-phenylphenol, 1 mM EDTA, 0.025% Tween 20 and  $5 \times 10^{-5}$  M acridan 37.

20      Figure 5 is a graph showing the time profile of chemiluminescence resulting from reaction of  $1.4 \times 10^{-15}$  moles of HRP at 25 °C with 40  $\mu$ L of a reagent comprising 0.01 M tris buffer, pH 8.0, 0.5 mM urea peroxide, 0.1 mM p-phenylphenol, 1 mM EDTA, 0.025% Tween 20 and  $5 \times 10^{-5}$  M acridan 38. Light production ensued upon mixing and reached maximum intensity in 1 min.

25      Figure 6 is a graph relating the amount of HRP to the maximum chemiluminescence intensity at 30 min emitted by 100  $\mu$ L of a reagent containing acridan 39 triggered at room temperature. Chemiluminescence emission was initiated by addition of 10  $\mu$ L of solutions of HRP containing between  $1.4 \times 10^{-15}$  to  $1.4 \times 10^{-20}$  moles to 100  $\mu$ L of reagent composition 30 comprising 0.01 M tris buffer, pH 8.0, 0.5 mM urea peroxide,

0.1 mM p-phenylphenol, 1 mM EDTA, 0.025% Tween 20 and  $5 \times 10^{-5}$  M acridan 39.

Figure 7 is a graph showing the time profile of chemiluminescence resulting from reaction of  $3.5 \times 10^{-16}$  moles of HRP at 25 °C with 100 µL of a reagent comprising 0.01 M tris buffer, pH 8.0, 0.5 mM urea peroxide, 0.1 mM p-phenylphenol, 1 mM EDTA, 0.025% Tween 20 and  $5 \times 10^{-5}$  M acridan 50. Light production ensued upon mixing and reached maximum intensity in 7 min.

Figure 8 is a graph relating the amount of HRP to the maximum chemiluminescence intensity at 15 min emitted by 100 µL of a reagent containing acridan 43 triggered at room temperature. Chemiluminescence emission was initiated by addition of 10 µL of solutions of HRP containing between  $1.4 \times 10^{-15}$  to  $1.4 \times 10^{-19}$  moles to 100 µL of a reagent composition comprising 0.055 M tris buffer, pH 8.6, 0.25 mM urea peroxide, 0.05 mM p-phenylphenol, 0.5 mM EDTA, 0.0125% Tween 20, 1 mM CTAB and  $6.6 \times 10^{-4}$  M acridan 43.

Figure 9 is a graph demonstrating the enhancement of chemiluminescence by the use of a fluorescent energy transfer agent. Reagent compositions comprising 0.055 M tris buffer, pH 8.6, 0.25 mM urea peroxide, 0.05 mM p-phenylphenol, 0.5 mM EDTA, 0.0125% Tween 20, 1 mM CTAB and  $3.3 \times 10^{-4}$  M compound 46 alone or with 50 µM DBA were tested for production of chemiluminescence by reacting a 100 µL aliquot with  $3.5 \times 10^{-15}$  moles of HRP.

Figure 10 is a graph showing the time profile of chemiluminescence resulting from reaction of  $3.5 \times 10^{-15}$  moles of HRP at 25 °C with 100 µL of a reagent comprising 0.055 M tris buffer, pH 8.6, 0.25 mM urea peroxide, 0.05 mM p-phenylphenol, 0.5 mM EDTA, 0.0125% Tween 20 and

3.3 x 10<sup>-4</sup> M compound 48.

Figure 11 is a graph showing the time profile of chemiluminescence resulting from reaction of 3.3 x 10<sup>-15</sup> moles of HRP at 25 °C with 100 µL of a reagent comprising 0.055 M tris buffer, pH 8.6, 0.25 mM urea peroxide, 0.05 mM p-phenylphenol, 0.5 mM EDTA, 0.0125% Tween 20 and 3.3 x 10<sup>-4</sup> M compound 49.

Figure 12 is an image of an x-ray film from a Western blot assay of β-galactosidase via an HRP-labeled antibody on a PVDF membrane with a chemiluminescent reagent composition. Dilutions of β-galactosidase containing from 5000, 1000, 180, 30 and 5 pg, respectively, of protein were detected with a reagent comprising 0.055 M tris buffer, pH 8.6 containing 0.66 mM acridan phosphate 5, 0.05 mM p-phenylphenol, 0.25 mM urea peroxide, 0.5 mM EDTA, 0.0125% Tween 20 by exposing the membrane to X-ray film for 30 s after a 14 min incubation.

Figure 13 is an image of an x-ray film from a similar Western blot experiment using a nitrocellulose membrane. The image was obtained by exposing the membrane to x-ray film for 5 min after a 10 min incubation time.

#### DESCRIPTION OF THE PREFERRED EMBODIMENTS

##### Definitions:

Alkyl - A branched, straight chain or cyclic hydrocarbon group containing from 1-20 carbons. Lower alkyl as used herein refers to those alkyl groups containing up to 8 carbons.

Alkenyl - A branched, straight chain or cyclic hydrocarbon group containing at least one C-C double bond and containing from 2-20 carbons. Lower alkenyl as used herein refers to

those alkenyl groups containing up to 8 carbons.

Alkynyl - A branched or straight chain hydrocarbon group containing at least one C-C triple bond and containing from 2-20 carbons. Lower alkynyl as used herein refers to those 5 alkynyl groups containing up to 8 carbons.

Analyte - A substance the presence or amount of which is to be measured in a sample by an assay. Analytes include organic and biological molecules to which a specific binding partner having a specific binding affinity exists. Exemplary 10 analytes include, without limitation, single stranded or double stranded DNA, RNA, DNA-RNA complexes, oligonucleotides, antibodies, antibody fragments, antibody-DNA chimeras, antigens, haptens, proteins, lectins, avidin, streptavidin and biotin. Other exemplary analytes also 15 include hydrolytic enzymes, inhibitors of hydrolytic enzymes and dihydroxyaromatic compounds.

Aryl - An aromatic ring-containing group containing 1 to 5 carbocyclic aromatic rings, which can be substituted with 1 or more substituents other than H.

Biomedical analysis - Analyses of samples of biological 20 origin for analytes of interest. The analyses can be immunoassays, western blots, northern blots, Southern blots, DNA hybridization assays, DNA sequence analysis, colony hybridizations, gene expression analysis, high throughput 25 drug screening, detection of infectious agents or pathogens and the like.

Glycosyl - Residues of carbohydrate groups including hexoses and pentoses and contain one or more sugar unit. Examples include fructose, galactose, glucose, glucuronate, 30 mannose, ribose, N-acetylglucosamine and the like.

Halogen - Fluorine, chlorine, bromine or iodine atoms.

Heteroaryl - An aromatic ring-containing group containing 1 to 5 carbocyclic aromatic rings in which at least one of the ring carbon atoms is replaced with a nitrogen, oxygen or sulfur atom and which can be substituted with 1 or more 5 substituents other than H.

Luminescent - capable of emitting light when excited to an electronic excited state. The light can be emitted either as fluorescence when decaying from a singlet excited state or as phosphorescence when decaying from a triplet excited state.

10 Peroxide - A compound containing an O-O bond, preferably hydrogen peroxide or a complex of hydrogen peroxide such as urea peroxide, perborate or percarbonate. Alkyl

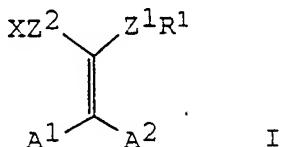
15 Sample - A fluid containing or suspected of containing one or more analytes to be assayed. Typical samples which are analyzed by the chemiluminescent reaction method are biological samples including body fluids such as blood, plasma, serum, urine, semen, saliva, cell lysates, tissue extracts and the like. Other types of samples include food samples and environmental samples such as soil or water.

20 Specific binding pair - Two substances which exhibit a mutual binding affinity. Examples include antigen-antibody, hapten-antibody or antibody-antibody pairs, complementary oligonucleotides or polynucleotides, avidin-biotin, streptavidin-biotin, hormone-receptor, lectin-carbohydrate, 25 IgG-protein A, nucleic acid-nucleic acid binding protein and nucleic acid-anti-nucleic acid antibody.

Substituted - Refers to the replacement of at least one hydrogen atom on a group by a non-hydrogen group. It should be noted that in references to substituted groups it is 30 intended that multiple points of substitution can be present unless clearly indicated otherwise.

It has been unexpectedly discovered that compounds of formula I below react with a peroxide and a peroxidase to generate chemiluminescence. Compounds of the present invention which produce chemiluminescence in the presence of a peroxidase comprise a carbon-carbon double bond substituted at one terminus of the double bond with two atoms selected from oxygen and sulfur atoms and have the formula I:

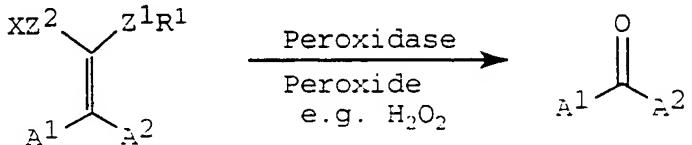
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wherein z<sup>1</sup> and z<sup>2</sup> are independently selected from O and S atoms, R<sup>1</sup> is an organic group containing from 1 to about 50 non-hydrogen atoms, X is a group containing from 1 to about 50 non-hydrogen atoms and A<sup>1</sup> and A<sup>2</sup> are groups selected so that an electronic excited state product A<sup>1</sup>A<sup>2</sup>C=O\* results upon reaction of I with a peroxidase according to the reaction below.

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The groups A<sup>1</sup>, A<sup>2</sup>, z<sup>1</sup>, z<sup>2</sup>, X and R<sup>1</sup> are selected so that the resulting compound I will have an electron-rich C-C double bond. In general, most compounds of general formula I having z<sup>1</sup> and z<sup>2</sup> selected from O and S atoms have a sufficiently electron-rich C-C double bond. Compounds in which A<sup>1</sup> and/or A<sup>2</sup> are strongly electron-withdrawing groups may not function and are not preferred.

The group R<sup>1</sup> can be any organic group containing from 1 to about 50 non-hydrogen atoms selected from C, N, O, S, P, Si and halogen atoms which allows light production. By the

latter is meant that when a compound of formula I is reacted with a peroxidase and a peroxide the light is produced and can involve the production of one or more chemiluminescent intermediates. Groups which can function as the R<sup>1</sup> group 5 include, without limitation, alkyl, substituted alkyl, aryl, substituted aryl, aralkyl and substituted aralkyl groups. Substituent groups other than H atoms, such as ionic groups or polar groups, can be incorporated in various numbers and at selected positions on the carbon chain or ring of R<sup>1</sup> in 10 order to modify the properties of the compound or to provide for convenience of synthesis. Such properties include, for example, chemiluminescence quantum yield, rate of reaction with the enzyme, maximum intensity of light emission, duration of light emission, wavelength of light emission, 15 solubility in the reaction medium. One or more groups which permit covalent coupling to another molecule such as a specific binding partner can also be included as substituents on R<sup>1</sup>. Exemplary specific substituents and their effects are illustrated in the specific examples below, which, however, 20 do not limit the scope of the invention.

The group X is selected from substituted or unsubstituted alkyl, substituted or unsubstituted aryl, substituted or unsubstituted aralkyl groups of 1-20 carbon atoms, substituted or unsubstituted alkyl or aryl carbonyl groups 25 having from 1-20 carbon atoms, tri(C<sub>1</sub>-C<sub>8</sub> alkyl)silyl groups, an SO<sub>3</sub><sup>-</sup> group, glycosyl groups and phosphoryl groups of the formula PO(OR')(OR'') wherein R' and R'' are independently selected from substituted or unsubstituted alkyl, substituted or unsubstituted aryl and substituted or unsubstituted aralkyl groups of 1-20 carbon atoms, trialkylsilyl groups, 30 alkali metal cations, alkaline earth cations, ammonium and

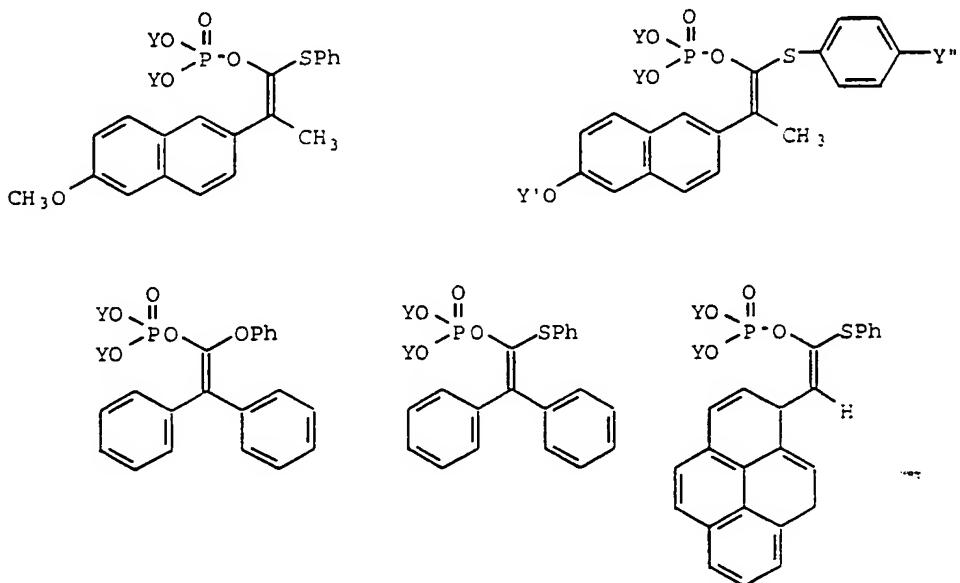
phosphonium cations. Substituted alkyl groups will contain at least one group other than a hydrogen atom, such as ionic groups or polar groups, and can be incorporated at selected positions on the carbon chain or ring of R' or R" in order to 5 modify the properties of compound I or to provide for convenience of synthesis. Exemplary substituted alkyl groups include a cyanoethyl group or a trimethylsilylethyl group.

The groups A<sup>1</sup> and A<sup>2</sup> are independently selected from hydrogen or organic groups which upon reaction of compound I 10 with peroxide and a peroxidase form an electronic excited state product A<sup>1</sup>A<sup>2</sup>C=O\* including, without limitation, hydrogen, alkyl, substituted alkyl, aryl, substituted aryl, aralkyl and substituted aralkyl groups, heteroaryl, substituted heteroaryl, alkenyl, alkynyl, alkoxy, aryloxy, 15 alkylamino, arylamino, alkylthio and arylthio groups provided that at least one is not hydrogen. The groups A<sup>1</sup> and A<sup>2</sup> can be joined together to form a heterocyclic or carbocyclic ring which includes the carbon atom separating A<sup>1</sup> and A<sup>2</sup>. In general the groups A<sup>1</sup> and A<sup>2</sup> will contain from 1-50 non- 20 hydrogen atoms selected from C, N, O, S, P and halogens and more usually from 1-20 non-hydrogen atoms.

In a first group of preferred compounds of formula I, one of A<sup>1</sup> and A<sup>2</sup> is a substituted or unsubstituted aryl group and the other is selected from alkyl, substituted alkyl, aryl, 25 substituted aryl, aralkyl, substituted aralkyl, heteroaryl, substituted heteroaryl, alkenyl, alkynyl, alkoxy, aryloxy, alkylamino, arylamino, alkylthio and arylthio. Preferably at least one of the aryl groups is substituted with at least one group selected from amino, alkylamino, dialkylamino and OY' 30 where Y' is hydrogen or an alkali metal ion. The aryl group comprises 1-4 fused carbocyclic or heterocyclic 5 or 6-

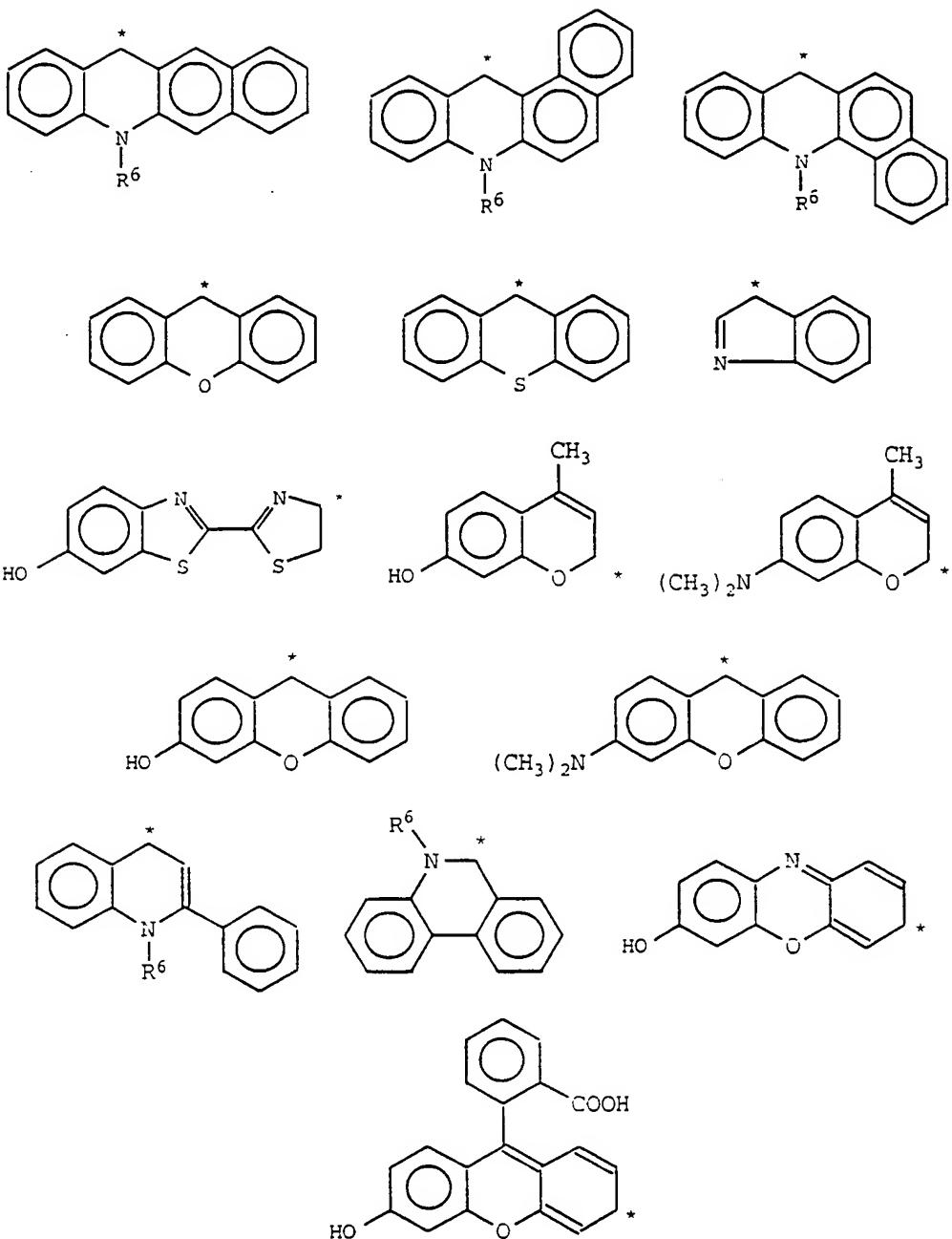
membered rings. When one or more of the rings is a heterocyclic ring, the heteroatoms in the ring are selected from N, O and S atoms. Preferred aryl groups are phenyl, naphthyl, anthryl and pyrenyl any of which can be substituted with non-hydrogen substituents. More preferred are phenyl and naphthyl groups.

Particular embodiments of compounds of formula I which are reactive according to the methods of the present invention to produce chemiluminescence include as examples compounds having the structures:



wherein Y is hydrogen, an alkali metal ion or a substituted or unsubstituted alkyl, substituted or unsubstituted aryl, substituted or unsubstituted aralkyl or trialkylsilyl group,

Y' is an alkali metal ion, an alkyl carboxy ester, aryl carboxy ester, substituted or unsubstituted alkyl, substituted or unsubstituted aryl, substituted or unsubstituted aralkyl group or trialkylsilyl group and Y" is hydrogen or halogen, in particular a chlorine atom. Although only one double bond isomer is depicted for these structures it is realized that either isomer or mixtures of the two can



25 In all of the above compounds of formula III and IV, the  
groups R<sup>2</sup> - R<sup>5</sup> each are independently H or a substituent  
group which permits the light to be produced and generally  
contain from 1 to 50 atoms selected from C, N, O, S, P and  
halogen atoms. Representative substituent groups which can be  
30 present include, without limitation, alkyl, substituted  
alkyl, aryl, substituted aryl, aralkyl, alkenyl, alkynyl,

alkoxy, aryloxy, halogen, amino, substituted amino, carboxyl, carboalkoxy, carboxamide, cyano, and sulfonate groups. Either or both pairs of adjacent groups, i.e. R<sup>2</sup> - R<sup>3</sup> or R<sup>4</sup> - R<sup>5</sup>, can be joined together to form a carbocyclic or heterocyclic ring

5 system comprising at least one 5 or 6-membered ring which is fused to the ring bearing the exocyclic double bond. Such fused heterocyclic rings can contain N, O or S atoms and can contain ring substituents other than H such as those mentioned above.

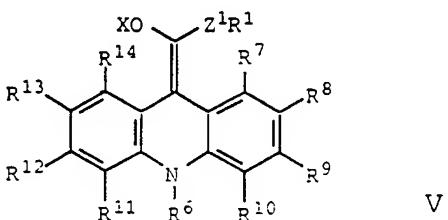
10 In all of the above compounds, the group R<sup>6</sup> is an organic group containing from 1 to 50 atoms non-hydrogen atoms selected from C, N, O, S, P and halogen atoms in addition to the necessary number of H atoms required satisfy the valencies of the atoms in the group. More preferably R<sup>6</sup> contains from 1 to 20 non-hydrogen atoms. The organic group is preferably selected from the group consisting of alkyl, substituted alkyl, aryl, substituted aryl and aralkyl groups. More preferred groups for R<sup>6</sup> include substituted or unsubstituted C<sub>1</sub>-C<sub>4</sub> alkyl groups, substituted or unsubstituted benzyl groups, alkoxyalkyl and carboxyalkyl groups.

15 Substituent groups can be incorporated in various quantities and at selected ring or chain positions in the heterocyclic ring in order to modify the properties of the compound or to provide for convenience of synthesis of the final phosphate compound. Such properties include, e.g. chemiluminescence quantum yield, rate of reaction with the enzyme, maximum light intensity, duration of light emission, wavelength of light emission and solubility in the reaction medium. Specific substituents and their effects are illustrated in the specific examples below, which, however, are not to be considered limiting the scope of the invention

in any way.

A preferred class of compounds have the formula V below wherein R<sup>1</sup> is an aryl ring group containing at least one carbocyclic or heterocyclic aromatic ring and which can be 5 further substituted or a substituted or unsubstituted alkyl group, Z<sup>1</sup> is selected from O and S atoms and X and R<sup>6</sup> are as defined above.

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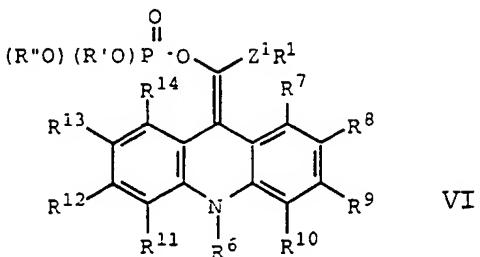


20

The groups R<sup>7</sup> to R<sup>14</sup>, which can be the same or different, each 15 are a substituent which can contain from 1 to 50 atoms selected from C, H, N, O, S, P and halogen atoms and which permit the light to be produced and can include, without limitation, alkyl, substituted alkyl, aryl, substituted aryl, aralkyl, alkenyl, alkynyl, alkoxy, aryloxy, halogen, amino, 20 substituted amino groups, carboxyl, carboalkoxy, carboxamide, cyano, and sulfonate groups. It is preferred that R<sup>7</sup> to R<sup>14</sup> are selected from hydrogen, halogen and alkoxy groups such as methoxy, ethoxy, t-butoxy and the like. A preferred group of compounds has one of R<sup>8</sup>, R<sup>9</sup>, R<sup>12</sup> or R<sup>13</sup> as a chlorine and the 25 other of R<sup>7</sup> to R<sup>14</sup> are hydrogen atoms. More preferred are compounds having the formula VI where Z and R<sup>1</sup> are as defined above, X is a phosphoryl group -PO(OR')(OR'') wherein R' and R'' are independently selected from substituted or unsubstituted alkyl, substituted or unsubstituted aryl and substituted or 30 unsubstituted aralkyl groups of 1- 20 carbon atoms, trialkylsilyl groups, alkali metal cations, alkaline earth

cations, ammonium and phosphonium cations.

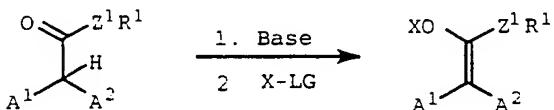
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VI

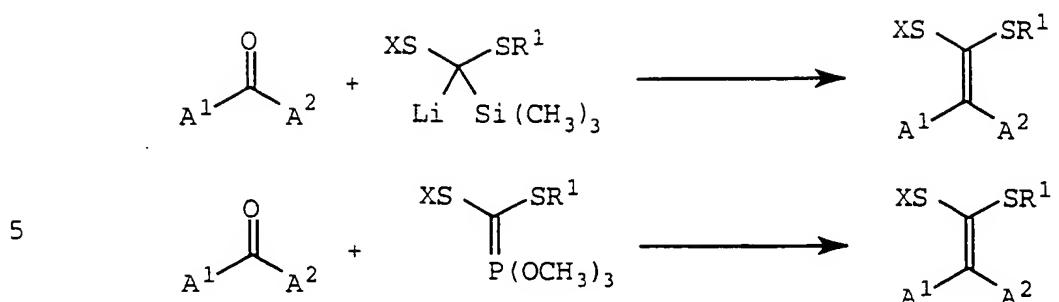
Preferably at least one of R' and R'' is an alkali metal cation and more preferably both are. Among the alkali metals, lithium, sodium and potassium are preferred.

10 Compounds of formula I can be prepared by various methods. In a preferred method, when Z<sup>2</sup> groups is O and Z<sup>1</sup> is O or S, compound I can be prepared by reacting the enolate of an ester or thioester with a reagent of the formula X-LG where LG represents a leaving group according to the scheme  
15 below.

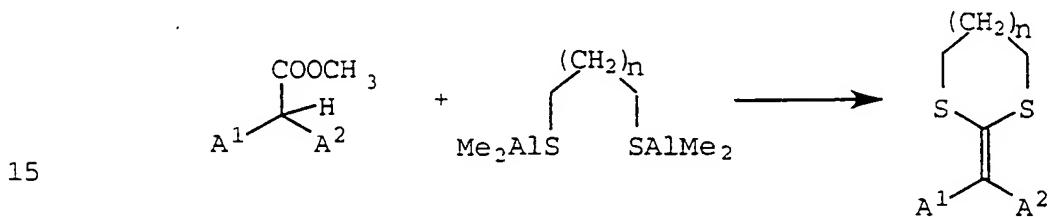


Typical leaving groups include halogens, such as chloride, bromide and iodide, sulfonates such as methanesulfonate and p-toluenesulfonate and trifluoromethanesulfonate, carboxylates such as acetate and benzoate particularly when X is an acyl group in which case X-LG would be an acid anhydride, sulfates such as methosulfate, and other groups such as imidazole, triazole and tetrazole, maleimide, succinimidoxyl groups.

Methods of preparing compounds of formula I where both Z groups are S atoms include nucleophilic addition of a lithiosilane compound or a phosphorus ylide to a suitable 30 carbonyl compound according to the two schemes below (F.A. Carey, A.S. Court, J. Org. Chem., 37, 1926-29, (1972)).



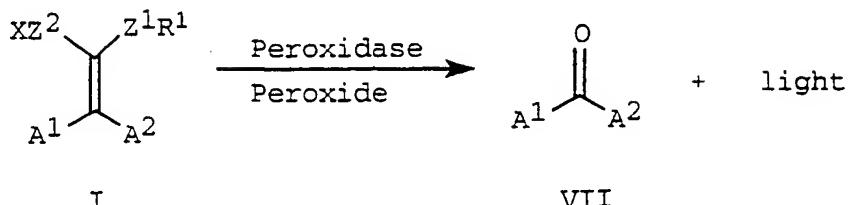
In another method, an ester is converted to a ketene-dithioacetal by reaction with a bis(dialkylaluminum)-dithiol reagent as disclosed in E.J. Corey and A.P. Kozikowski, Tetrahedron Lett., 925-8 (1975) and shown below.



In yet another method, an anion of an active methylene group is reacted with  $\text{CS}_2$  and the dithiocarboxylate is reacted with a reagent  $\text{R}_1\text{-LG}$  containing the  $\text{R}_1$  group to form a dithioester. An example of the latter methodology is disclosed in I. Shahak and Y. Sasson, Tetrahedron Lett., 4207-10 (1973). The dithioester is converted to the enolate and reacted with a reagent of the formula  $\text{X-LG}$ .

Another aspect of the present invention is the use of  
25 compounds of any of formulas I-VI in a method to produce  
chemiluminescence by reaction with a peroxidase. Reaction of  
a compound of formula I-VI with a peroxidase and a peroxide  
in an aqueous buffer solution produces easily detected  
chemiluminescence. Light intensity reaches a maximum level  
30 within minutes at room temperature when the reaction is  
conducted at alkaline pH. The reaction is conducted

optionally in the presence of an enhancer.



5

I

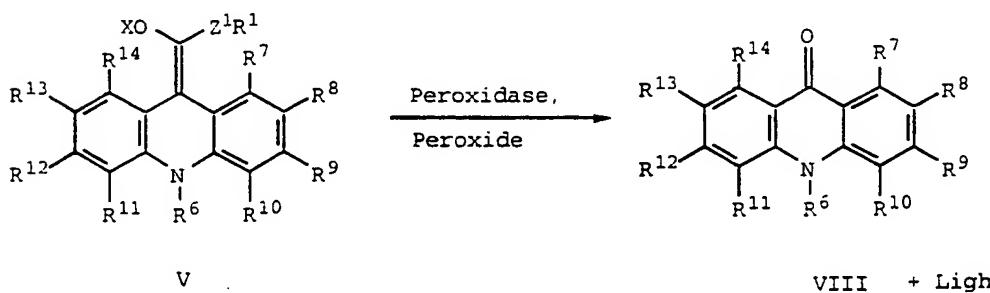
VII

10

While we do not wish to put forth a specific mechanistic explanation for this discovery at this point, it is believed that the light is emitted from the electronically excited state of VII. A necessary condition for the production of light is that the reaction produces sufficient energy to form the excited state of VII. If VII\* is luminescent, then chemiluminescence is produced from the reaction via emission from the excited state of VII. If composition VII\* is not significantly luminescent, then chemiluminescence can be produced by the inclusion of a luminescent energy acceptor.

• In a preferred method of producing chemiluminescence, compound I is reacted with a peroxidase, a peroxide and an enhancer in an alkaline buffer with a pH between about 8 and 10 to produce a continuous chemiluminescence signal which commences upon reaction of the enzyme and the compound I. Analytical sensitivity can be increased by incorporation of a non-ionic surfactant as will be described in more detail below.

25



30

V

VIII + Light

In a preferred method of producing light from the

reaction of compound V with a peroxidase, the reaction is performed at a temperature between 5 °C and 50 °C, preferably between 20 °C and 40 °C in an aqueous buffer solution at a pH between 7 and 10.5, preferably between 8.5 and 10. Compound V 5 is used at a concentration between 1 µM and 20 mM, preferably between 10 µM and 1 mM. The enzyme can be a free peroxidase or a peroxidase conjugate. Light is emitted from the excited state of VIII.

Compounds of the present invention typically produce 10 light over a 100-200 nm wide band of emission, which exhibits a maximum intensity at wavelengths in the near ultraviolet to the visible region of the electromagnetic spectrum. Typical wavelengths of maximum intensity  $\lambda_{\text{max}}$  in the range of 350-500 nm. It is contemplated that compounds of formula I bearing a 15 covalently linked fluorophore could undergo intramolecular energy transfer resulting in emission at longer wavelengths from the excited state of the fluorophore.

More than one compound of formula I can be used concurrently in a method for producing light by the action of 20 a peroxidase. It can be advantageous in some instances to simultaneously react two or more compounds of formula I with the peroxidase. When the two or more compounds have differing luminescent or physical properties, the combination of the two may be desirable to produce a light emitting reaction 25 with characteristics not readily achievable through the use of any one compound. Examples of luminescent and physical properties which can differ between compounds I include emission spectrum, duration of light emission, enzyme turnover, rate of rise of emission to maximum, 30 hydrophobicity/hydrophilicity and solubility.

The peroxide component is any peroxide or alkyl

hydroperoxide capable of reacting with the peroxidase.

Preferred peroxides include hydrogen peroxide, urea peroxide, and perborate salts.

The peroxidase which can undergo the chemiluminescent reaction include lactoperoxidase, microperoxidase, myeloperoxidase, haloperoxidase, e.g. vanadium bromoperoxidase, horseradish peroxidase, fungal peroxidases such as lignin peroxidase and peroxidase from *Arthromyces ramosus* and Mn-dependent peroxidase produced in white rot fungi, and soybean peroxidase. Other peroxidase mimetic compounds which are not enzymes but possess peroxidase-like activity including iron complexes and Mn-TPPS<sub>4</sub> (Y.-X. Ci, et al., *Mikrochem. J.*, 52, 257-62 (1995)) are known which catalyze the chemiluminescent oxidation of luminol are explicitly considered to be within the scope of the meaning of peroxidase as used herein. Conjugates or complexes of a peroxidase and a biological molecule can also be used in the method for producing chemiluminescence, the only proviso being that the conjugate display peroxidase activity.

Biological molecules which can be conjugated to one or more molecules of a peroxidase include DNA, RNA, oligonucleotides, antibodies, antibody fragments, antibody-DNA chimeras, antigens, haptens, proteins, lectins, avidin, streptavidin and biotin. Complexes including or incorporating a peroxidase such as liposomes, micelles, vesicles and polymers which are functionalized for attachment to biological molecules can also be used in the methods of the present invention.

Incorporation of certain enhancer compounds into the reaction mixture promotes the reactivity of the enzyme.

Included among these enhancers are phenolic compounds and aromatic amines known to enhance other peroxidase reactions

method for detecting hydrogen peroxide in an assay procedure by a chemiluminescent reaction with a compound of formula I and a peroxidase enzyme, wherein the amount of light produced is related to the amount of the peroxide present. It will be  
5 apparent to those skilled in the art of chemiluminescent assays that the present methods can be used to detect oxidase enzymes and dehydrogenase enzymes. These enzymes generate hydrogen peroxide through reduction of oxygen and oxidation of their native substrates. The hydrogen peroxide thereby  
10 produced can then be further reacted either concurrently as it is generated or in a subsequent step with compound I of the present invention and a peroxidase to produce light. A property of the light produced is then related to the amount of the oxidase or dehydrogenase enzyme. Further the oxidase  
15 or dehydrogenase enzyme may be present as a conjugate to a biological molecule or a member of a specific binding pair in an assay for an analyte.

The reaction of a compound of formula I with a peroxidase to produce chemiluminescence constitutes a rapid and sensitive method for detecting the presence or amount of the peroxidase. Use of the present method can therefore be made for the purpose of determining the presence or quantity of a peroxidase in a sample by measuring the amount or intensity of light produced by reaction of the sample with a compound  
20 of formula I. Such a determination can find use e.g. in detecting the peroxidase activity of mammalian blood as evidence in forensic investigations.

A second area of application for the chemiluminescent measurement of peroxidase activity is in the detection and  
30 measurement of enzyme inhibitors. Inhibitors can act reversibly by acting as a substrate in competition with a second

substrate such as the compounds of the present invention. Another mode of inhibition known as suicide inhibition acts irreversibly by deactivating the enzyme. For example, peroxidase inhibitors include cyanide, sulfide and high concentrations of hydrogen peroxide. Further it is recognized that some substances are only inhibitory at certain concentrations and can be only partially inhibitory.

Measurement of the quantity or characteristics of an inhibitor, such as the inhibition constant  $K_i$ , or half-life for inhibition,  $t_{1/2}$ , are made by measuring the enzyme activity of a sample containing the enzyme in question in the presence of a substrate producing a detectable product and a quantity of the inhibitor. In a method of detecting an enzyme inhibitor according to the present invention, a compound of formula I produces light as the detectable product. Reaction of the enzyme and chemiluminescent compound is made in the presence and absence of the inhibitor substance and the results are compared to determine the presence or amount of the inhibitor. The effect of the inhibitor can have one or more of any of three effects, a decrease in light intensity, a slower rate of rise of light intensity or a delay period before light emission begins.

Techniques for performing enzyme assays are well known. With the guidance provided by the examples as taught herein, variations of procedures for preparing samples, determining appropriate quantities and ratios of reagents, reaction times, constructing calibration curves and the like will be within the ability of one of ordinary skill in the art to devise as a matter of routine experimentation.

Since the reaction is catalyzed by the peroxidase, exceedingly small quantities of the enzyme are sufficient to pro-

duce a detectable amount of light. Sensitivities below 1 attomol ( $1 \times 10^{-18}$  mol) have been achieved. The ability to detect such small amounts of peroxidases make the present chemiluminescent technology suitable for analyses of many

5 types of analytes using enzyme-linked assays. Such analyses and assays require the ability to detect small quantities of peroxidases due to low abundance of the analyte in the sample to be analyzed or to limited sample quantity. In this type of assay, a peroxidase is conjugated to one member of a

10 specific binding pair. An example is a chemiluminescent enzyme-linked immunoassays, such as the so-called enzyme-linked immunosorbent assay or ELISA. Such assays are commonly used in manual format as well as on automated multi-test immunoassay systems. In a typical immunoassay, the analyte

15 hapten, antigen or antibody is assayed by detecting the presence or amount of an enzyme-labeled specific binding partner for the analyte or an enzyme-labeled analog of the analyte. Various assay formats and the protocols for performing the immunochemical steps are well known in the art. These

20 assays fall broadly into two categories. Competitive assays feature an immunological binding of a specific antibody with the analyte and an analyte analog, e.g. a detectably labeled analyte molecule. Sandwich assays result by the sequential or simultaneous binding of two antibodies, one of which is

25 detectably labeled, with the analyte. The detectably labeled binding pair so formed can be assayed with the compounds and methods of the present invention. When the detectable label is the peroxidase enzyme, it is detected directly. When the detectable label is a member of another specific binding

30 pair, e.g. a hapten, a conjugate of its binding partner with a peroxidase is reacted first and the peroxidase then detect-

ed in accordance with the present methods. Measurement can be performed with enzyme-labeled species attached to a solid surface or support including beads, tubes, microwells, magnetic particles, test strips, membranes and filters such as are 5 in common use in the art. The detectable enzyme-labeled species can also be present free in solution or enclosed within an organized assembly such as a liposome in which case a lytic agent is employed to lyse the liposome and free the detectable enzyme.

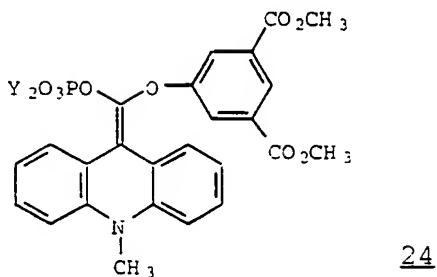
10 Another exemplary use is the detection of proteins by the technique of Western blotting. A sample containing a protein of interest as the analyte is subject to electrophoretic separation. The separated proteins are transferred to a blotting membrane such as a nitrocellulose or PVDF membrane 15 by capillary action or with the aid of an electric field. Such transferred protein is typically detected with a specific primary antibody and an enzyme-labeled secondary antibody which recognizes and binds to the primary antibody. Visualization of marker enzyme activity reflects the presence of the 20 analyte protein. To adapt the methods of the present invention for Western blotting, an HRP conjugated secondary antibody can be employed and peroxidase activity measured with chemiluminescence using a compound of the present invention as the chemiluminescent reagent. Variations on this technique 25 such as using biotinylated antibodies and avidin-HRP are considered within the scope of assays able to be performed using the inventive methods.

In addition to the aforementioned antigen-antibody, hapten-antibody or antibody-antibody pairs, specific binding 30 pairs also can include complementary oligonucleotides or polynucleotides, avidin-biotin, streptavidin-biotin, hormone-

19	Br
20	I
21	COCH <sub>3</sub>
22	CN
5	NO <sub>2</sub>
23	

as well as the compound 24 (Y=Na) and 24a (Y=CH<sub>2</sub>CH<sub>2</sub>CN) having the formula:

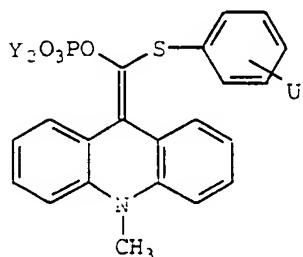
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and compounds 25-36 (Y=Na) and 25a-36a (Y=CH<sub>2</sub>CH<sub>2</sub>CN) having the formula:

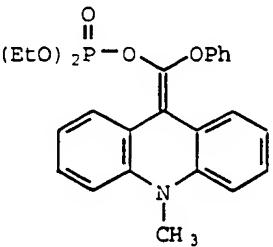
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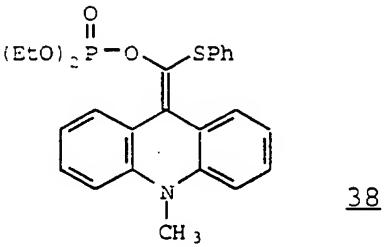
wherein U is p-I (25), p-CH<sub>3</sub> (26), m-OCH<sub>3</sub> (27), o-Cl (28), m-Cl (29), o-Br (30), m-Br (31), p-Br (32) and p-NO<sub>2</sub> (33) as well as compounds of this formula having a 3,4-dichloro- (34), 2,5-dichloro- (35) and 2,6-dichlorophenyl (36) group. All produce chemiluminescence when reacted with a peroxidase and a peroxide.

30

The following exemplary compounds were prepared and found to produce chemiluminescence according to the present methods.

7. Synthesis of Acridan Derivative 37.

A solution of phenyl 10-methylacridan-9-carboxylate (250 mg, 0.79 mmol) in THF was deprotonated with LDA at -78 °C. Simultaneously,  $(\text{EtO})_2\text{POCl}$  (205 mg, 1.2 mmol) and pyridine (94 mg, 1.2 mmol) were added via syringes and stirring continued for 15 min. The dry ice bath was removed and stirring continued for 2 h. The volatiles were removed and the product isolated from the residue chromatographically in two steps. A column chromatographic purification using 30% ethyl acetate /hexane allowed separation of the product containing a fluorescent impurity. Final purification was effected by prep. TLC using 10% ethyl acetate/ $\text{CH}_2\text{Cl}_2$ ;  $^1\text{H}$  NMR (acetone- $\delta_6$ )  $\delta$  1.08 (t, 6H), 3.46 (s, 3H), 3.76-3.97 (m, 4H), 6.79-7.91 (m, 13H).

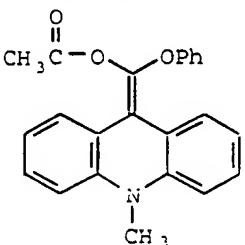
8. Synthesis of Acridan Derivative 38.

A solution of phenyl 10-methylacridan-9-thiocarboxylate (1.0 g, 3 mmol) in THF was deprotonated with LDA at -78 °C. Simultaneously,  $(\text{EtO})_2\text{POCl}$  (958 mg, 5 mmol) and pyridine (2.5 mL, 3 mmol) were added via syringes and stirring continued for 15 min. The dry ice bath was removed and stirring continued for 2 h. The volatiles were removed and the product isolated from the residue chromatographically in two steps. A

column chromatographic purification using 30-100% ethyl acetate/hexane allowed separation of the product containing blue and green fluorescent impurities. Final purification was effected by prep. TLC using 12% ethyl acetate/CH<sub>2</sub>Cl<sub>2</sub>; <sup>1</sup>H NMR (acetone-d<sub>6</sub>) δ 1.01 (t, 6H), 3.49 (s, 3H), 3.74-3.96 (m, 4H), 5 6.91-7.45 (m, 11H), 7.78 (d, 1H), 7.99 (d, 1H).

9. Synthesis of Acridan Derivative 39.

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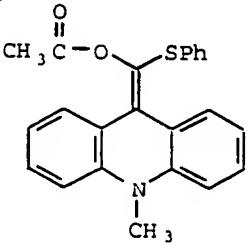
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A solution of phenyl 10-methylacridan-9-carboxylate (311 15 mg, 1 mmol) in THF was added dropwise to a solution of LDA at -78 °C. After 30 minutes at -78 °C, acetic anhydride (161.3 mg, 1.6 mmol) was added via syringe and the dry ice bath was removed. After one hour, the volatiles were removed and the product isolated from the residue chromatographically. A 20 column chromatographic purification using 5 % ethyl acetate /hexane provided a 90 mg pure fraction as a white solid and a second fraction (250 mg) which contained some starting material; <sup>1</sup>H NMR (CDCl<sub>3</sub>) δ 2.04 (s, 3H), 3.44 (s, 3H), 6.82-7.65 (m, 13H).

25

10. Synthesis of Acridan Derivative 40.

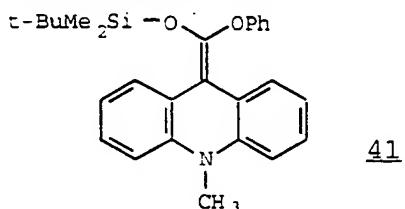
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A solution of phenyl 10-methylacridan-9-thiocarboxylate (1.05 g) in THF was deprotonated with LDA at -78 °C. Acetic anhydride (0.45 mL) in 10 mL of THF was added dropwise, the dry ice bath was removed and continued stirring over night.

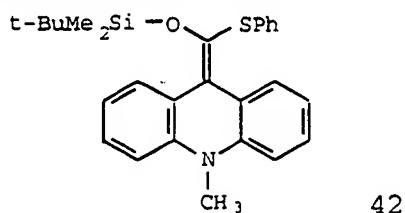
5 The volatiles were removed and the product isolated from the residue chromatographically. A column chromatographic purification using 5-20 % ethyl acetate/hexane provided 1.15 g of compound 40 as an off-white solid;  $^1\text{H}$  NMR ( $\text{CDCl}_3$ )  $\delta$  1.89 (s, 3H), 3.48 (s, 3H), 6.95-7.06 (m, 4H), 7.20-7.34 (m, 5H),  
10 7.40-7.44 (m, 2H), 7.62 (d, 1H), 7.79 (d, 1H).

11. Synthesis of Acridan Derivative 41.



A solution of phenyl 10-methylacridan-9-carboxylate (333.4 mg, 1.06 mmol) in THF was deprotonated with LDA at -78 °C for 30 min. The deep orange solution was treated with t-butyldimethylsilyl chloride (253.4 mg, 1.68 mmol) in 10 mL of dry THF. The dry ice bath was removed and stirring continued for 2 h. The volatiles were removed and the product isolated as an oil (212 mg) from the residue chromatographically using 5 % ethyl acetate/hexane;  $^1\text{H}$  NMR ( $\text{CDCl}_3$ )  $\delta$  -0.12 (s, 6H), 0.77 (s, 9H), 3.37 (s, 3H), 6.75-7.38 (m, 12H), 7.79 (dd, 1H).

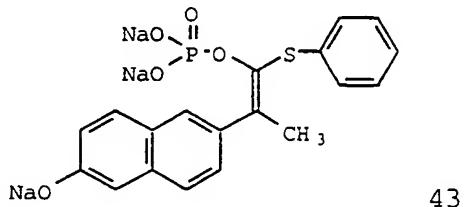
12. Synthesis of Acridan Derivative 42.



A solution of phenyl 10-methylacridan-9-thiocarboxylate (322.3 mg, 0.97 mmol) in THF was deprotonated with LDA at -78 °C. t-Butyldimethylsilyl chloride (270 mg, 1.8 mmol) in 5 mL of dry THF was added rapidly, the dry ice bath was removed and stirring continued for 90 min. The volatiles were removed and 330 mg of the product isolated from the residue chromatographically using 5 % ethyl acetate/hexane as an oil which solidified on standing;  $^1\text{H}$  NMR ( $\text{CDCl}_3$ )  $\delta$  -0.09 (s, 6H), 0.73 (s, 9H), 3.43 (s, 3H), 6.84-7.01 (m, 4H), 7.16-7.47 (m, 7H), 7.73-7.76 (m, 1H), 7.90-7.93 (m, 1H).

13. Synthesis of Compound 43.

15



The E isomer is depicted here for illustration. Although substantially one isomer was formed, it is not known with certainty which isomer.

(a) A mixture of 2-(6-hydroxy-2-naphthyl)-propanoic acid (1.00 g) and benzenethiol (0.635 g) in 100 mL of dry THF was treated with 1.2 g of DCC by stirring over night. The mixture was evaporated to dryness and the residue washed with hexane and filtered. The residue was partitioned between  $\text{CH}_2\text{Cl}_2$  and water and the organic layer dried and evaporated. The crude thioester phenyl 2-(6-hydroxy-2-naphthyl)-propane-thioate was purified by column chromatography with 30% ethyl acetate /hexane;  $^1\text{H}$  NMR ( $\text{CDCl}_3$ )  $\delta$  1.66 (d, 3H), 4.14 (q, 1H), 5.30 (s, 1H), 7.09-7.74 (m, 11H);  $^{13}\text{C}$  NMR ( $\text{CDCl}_3$ )  $\delta$  18.63, 54.09, 103.02, 109.42, 118.35, 126.54, 126.97, 127.06, 127.88, 128.88, 129.18, 129.39, 129.82, 134.04, 134.52, 153.86,

199.78.

(b) The phenol group was protected as the pivalate ester by reacting the product of the previous step (2.5 g) with 1.1 mL of pivaloyl chloride in 3 mL of triethylamine. On completion of the reaction, the mixture was evaporated to dryness and the residue partitioned between  $\text{CH}_2\text{Cl}_2$  and water. The organic layer was washed with water followed by satd. NaCl, dried and evaporated. The crude thioester phenyl 2-(6-pivaloyloxy-2-naphthyl)-propanethioate was purified by column chromatography with 0-5 % ethyl acetate/hexane;  $^1\text{H}$  NMR ( $\text{CDCl}_3$ )  $\delta$  1.41 (s, 9H), 1.66 (d, 3H), 4.17 (q, 1H), 7.19-7.87 (m, 11H).

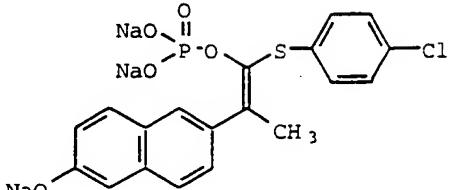
(c) Conversion of the thioester from step (b) to the enol bis(cyanoethyl)phosphate was effected by deprotonation of 2.0 g of the thioester with 1.5 eq. of LDA in dry THF at -78 °C and reacting the enolate with 0.71 mL of  $\text{POCl}_3$  and 0.62 mL of pyridine, followed by addition of 1.04 mL of 3-hydroxypropionitrile in 1.2 mL of pyridine. The reaction solution was filtered and evaporated. The product was isolated from the residue by column chromatography using 60 % ethyl acetate /hexane followed by a further wash with water to remove residual 3-hydroxypropionitrile. The product appeared to be substantially one isomer (43a);  $^1\text{H}$  NMR ( $\text{CDCl}_3$ )  $\delta$  1.39 (s, 9H), 2.38 (s, 3H), 2.67 (m, 4H), 4.25 (m, 4H), 7.2-7.8 (m, 11H);  $^{31}\text{P}$  NMR ( $\text{CDCl}_3$ )  $\delta$  -7.43.

(d) Compound 43a was deprotected by reacting 0.72 g in 35 mL of acetone containing 0.198 g of NaOH dissolved in 1 mL of water. The precipitated salt was washed with acetone, dissolved in ethanol and precipitated with acetone to produce 43;  $^1\text{H}$  NMR ( $\text{CD}_3\text{OD}$ )  $\delta$  2.34 (s, 3H), 6.80-7.44 (m, 11H);  $^{13}\text{C}$  NMR ( $\text{CD}_3\text{OD}$ )  $\delta$  21.26, 111.32, 124.15, 125.10, 125.08, 127.38, 127.90, 128.62, 129.35, 129.44, 135.79, 136.06, 136.14,

136.51, 139.31, 139.43, 140.07, 164.99;  $^{31}\text{P}$  NMR ( $\text{CD}_3\text{OD}$ )  $\delta$  6.24.

14. Synthesis of Compound 44.

5



44 E/Z

(a) A mixture of 2-(6-hydroxy-2-naphthyl)-propanoic acid (7.00 g) and 4-chlorobenzenethiol (6.22 g) in dry THF was treated with 8.85 g of DCC by stirring over night. The mixture was filtered and the filtrate evaporated to dryness. The residue was partitioned between  $\text{CH}_2\text{Cl}_2$  and water and the organic layer washed sequentially with water and satd. NaCl. Drying and evaporating the solvent produced the thioester phenyl 2-(6-hydroxy-2-naphthyl)-propanethioate which was purified by column chromatography with 20% ethyl acetate /hexane;  $^1\text{H}$  NMR ( $\text{CDCl}_3$ )  $\delta$  1.65 (d, 3H), 4.08-4.18 (m, 1H), 7.11-7.75 (m, 10H).

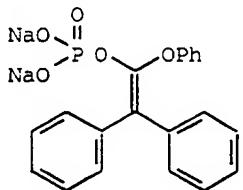
(b) The phenol group was protected as the pivalate ester. The thioester from the previous step (6.14 g) was reacted with pivaloyl chloride (2.89 g) and 5 mL of triethylamine. After evaporating the mixture to dryness, the residue was washed with water and satd. NaCl and dried over  $\text{Na}_2\text{SO}_4$ . Further purification was performed by chromatography with 5% ethyl acetate/hexane;  $^1\text{H}$  NMR ( $\text{CDCl}_3$ )  $\delta$  1.41 (s, 9H), 1.65-1.68 (d, 3H), 4.12-4.19 (q, 1H), 7.20-7.87 (m, 10H);  $^{13}\text{C}$  NMR ( $\text{CDCl}_3$ )  $\delta$  18.57, 27.22, 39.18, 54.21, 103.02, 118.35, 121.78, 126.57, 126.99, 128.33, 129.39, 131.43, 133.25, 136.74, 149.06, 177.32, 198.59.

(c) Conversion of the protected thioester to the enol bis(cyanoethyl)phosphate was effected by deprotonation of 2.2

g of the thioester with 1.5 eq. of LDA in dry THF at -78 °C and reacting the enolate with 1.5 eq. of  $\text{POCl}_3$  and 1.5 eq. of pyridine, followed by addition of 1.04 mL of 3-hydroxypropionitrile in 1.2 mL of pyridine. The reaction solution was 5 evaporated, and the residue partitioned between  $\text{CH}_2\text{Cl}_2$  and water. The organic layer was washed sequentially with water and satd. NaCl, dried and evaporated. The product was isolated from the residue chromatographically using 65 % ethyl acetate/hexane as a mixture of isomers (44a E/Z);  $^1\text{H}$  NMR ( $\text{CDCl}_3$ )  $\delta$  1.40 (s, 9H), 2.36 & 2.36 (2s, 3H), 2.72-2.76 (m, 4H), 4.24-4.35 (m, 4H), 7.17-7.81 (m, 10H);  $^{31}\text{P}$  NMR ( $\text{CDCl}_3$ )  $\delta$  10 -7.07.

(d) Compound 44a was deprotected by reacting 0.80 g in 60 mL of acetone containing 0.26 g of NaOH dissolved in 1 mL of 15 water. The precipitated salt was washed with acetone and dried producing compound 44 as a mixture of isomers (44 E/Z);  $^1\text{H}$  NMR ( $\text{D}_2\text{O}$ )  $\delta$  2.19 (s, 3H), 6.79-7.54 (m, 11H);  $^{31}\text{P}$  NMR ( $\text{D}_2\text{O}$ )  $\delta$  2.90.

20 15. Synthesis of Compound 45.



45

25 (a) Diphenylacetic acid (3.12 g) was converted to the acid chloride by refluxing in 50 mL of  $\text{SOCl}_2$  for 2.5 hours and esterified with 1.52 g of phenol in 50 mL of  $\text{CH}_2\text{Cl}_2$  containing ca. 2 mL of  $\text{Et}_3\text{N}$  over night. The volatiles were removed in vacuo and the residue partitioned between hexane and water.

30 The organic layer was dried and the ester used without further purification;  $^1\text{H}$  NMR ( $\text{CDCl}_3$ )  $\delta$  5.27 (s, 1H), 7.05-7.44

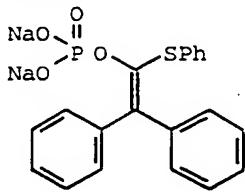
(m, 15H);  $^{13}\text{C}$  NMR ( $\text{CDCl}_3$ )  $\delta$  57.09, 121.44, 125.99, 127.54, 128.70, 128.82, 129.42, 138.26, 150.79, 171.04.

(b) The ester was converted to the enol bis(cyanoethyl)phosphate by deprotonation of 3.0 g with 1.1 eq. of LDA in dry THF at -78 °C for 30 min. and reacting the enolate with 1.15 eq. of  $\text{POCl}_3$  and 1.15 eq. of pyridine for 3 hours as the reaction warmed to room temperature. 3-Hydroxypropionitrile (2.05 mL) in 4.8 mL of pyridine was added and the reaction stirred over night. The reaction solution was evaporated, and the residue partitioned between  $\text{CH}_2\text{Cl}_2$  and water. The organic layer was washed sequentially with water and satd. NaCl, dried and evaporated. The product was isolated from the residue chromatographically using 70 % ethyl acetate/hexane (45a);  $^1\text{H}$  NMR ( $\text{CDCl}_3$ )  $\delta$  2.30-2.45 (m, 4H), 3.69-3.84 (m, 4H), 7.08-7.45 (m, 15H).

(c) Compound 45a was deprotected by reacting 1.04 g in 30 mL of acetone containing 0.18 g of NaOH dissolved in 1 mL of water over night. The precipitated salt was washed with acetone and dried producing compound 45 (0.5 g);  $^1\text{H}$  NMR ( $\text{D}_2\text{O}$ )  $\delta$  7.00-7.56 (m, 15H);  $^{13}\text{C}$  NMR ( $\text{D}_2\text{O}$ )  $\delta$  110.51, 110.60, 116.21, 122.29, 126.60, 126.72, 128.26, 129.54, 129.87, 129.96, 139.01, 146.75, 146.87, 156.55, 201.63;  $^{31}\text{P}$  NMR ( $\text{D}_2\text{O}$ )  $\delta$  2.15.

### 15. Synthesis of Compound 46.

25



46

(a) Diphenylacetic acid (6.0 g) was converted to the acid chloride by refluxing in 30 mL of  $\text{SOCl}_2$  and esterified with 3.5 g of thiophenol in 50 mL of  $\text{CH}_2\text{Cl}_2$  containing ca. 10 mL of

$\text{Et}_3\text{N}$  over night. The solution was extracted sequentially with water, saturated  $\text{NaHCO}_3$  and brine. After drying over  $\text{Na}_2\text{SO}_4$ , the volatiles were removed in vacuo and the thioester used without further purification;  $^1\text{H NMR} (\text{CDCl}_3) \delta 5.31$  (s, 1H),

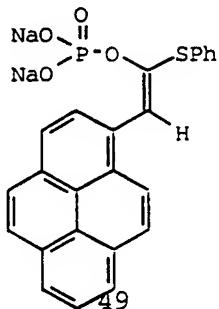
5 7.2-7.6 (m, 15H);

(b) The thioester was converted to the enol bis (cyanoethyl)phosphate by deprotonation of 3.0 g with 1.1 eq. of LDA in dry THF at -78 °C for 30 min. and reacting the enolate with 1.15 eq. of  $\text{POCl}_3$  and 1.15 eq. of pyridine for 10 3.5 hours as the reaction warmed to room temperature. 3-Hydroxy-propionitrile (2.05 mL) in 4.8 mL of pyridine was added and the reaction stirred over night. The reaction solution was evaporated, and the residue partitioned between  $\text{CH}_2\text{Cl}_2$  and water. The organic layer was washed sequentially 15 with water and satd.  $\text{NaCl}$ , dried and evaporated. The product was isolated from the residue chromatographically using 65 % ethyl acetate/hexane (46a);  $^1\text{H NMR} (\text{CDCl}_3) \delta 2.3-2.5$  (m, 4H), 3.62-3.82 (m, 4H), 7.2-7.45 (m, 15H).

(c) Compound 46a was deprotected by reacting 1.79 g in 20 50 mL of acetone containing 0.3 g of NaOH dissolved in 2 mL of water over night. The precipitated salt was washed with acetone and dried producing compound 46 (1.5 g);  $^1\text{H NMR} (\text{D}_2\text{O}) \delta 7.08-7.44$  (m, 15H);  $^{13}\text{C NMR} (\text{D}_2\text{O}) \delta 125.78, 127.23, 127.41,$  127.60, 128.11, 128.17, 129.11, 129.93, 129.54, 135.58, 25 135.67, 139.86, 140.74, 140.86, 141.62;  $^{31}\text{P NMR} (\text{D}_2\text{O}) \delta 2.30.$

#### 16. Synthesis of Compound 47.

30



49

47 E/Z

(a) A mixture of 1-pyreneacetic acid (3.00 g) and benzenethiol (1.27 g) in 100 mL of dry THF was treated with 5 2.38 g of DCC by stirring over night. The mixture was filtered and the filtrate evaporated to dryness. The residue was partitioned between  $\text{CH}_2\text{Cl}_2$  and water and the organic layer washed sequentially with satd.  $\text{NaHCO}_3$ , water and satd.  $\text{NaCl}$ . Drying and evaporating the solvent produced the thioester 10 phenyl 2-pyrenethioacetate which was purified by chromatography using 15% ethyl acetate/hexane;  $^1\text{H}$  NMR ( $\text{CDCl}_3$ )  $\delta$  4.66 (s, 2H), 7.35 (s, 5H), 8.02-8.30 (m, 9H);  $^{13}\text{C}$  NMR ( $\text{CDCl}_3$ )  $\delta$  109.23, 124.96, 125.51, 127.45, 127.66, 128.33, 129.15, 129.39, 134.49, 170.01.

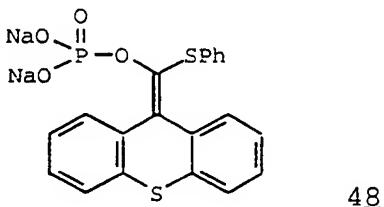
(b) Conversion of the thioester to the enol bis (cyanoethyl)phosphate was effected by deprotonation of 0.5 g of the thioester with 1.2 eq. of LDA in 30 mL of dry THF at - 78 °C and reacting the enolate with 1.2 eq. of  $\text{POCl}_3$  and 1.2 eq. of pyridine, followed by addition of 0.255 mL of 3- 15 hydroxypropionitrile in 0.30 mL of pyridine. The reaction solution was evaporated, and the residue partitioned between  $\text{CH}_2\text{Cl}_2$  and water. The organic layer was washed sequentially with water and satd.  $\text{NaCl}$ , dried and evaporated. The product was isolated from the residue chromatographically using 60 % 20 ethyl acetate/hexane as a 5:2 mixture of isomers (47a E/Z);  $^1\text{H}$  NMR ( $\text{CDCl}_3$ )  $\delta$  2.15-2.24 (m), 2.63-2.67 (m) 3.62-3.78 (m), 4.14-4.22 (m), 7.24-8.26 (m);  $^{31}\text{P}$  NMR ( $\text{CDCl}_3$ )  $\delta$  27.39, 28.16;  $^{13}\text{C}$  NMR ( $\text{CDCl}_3$ )  $\delta$  19.06, 19.15, 19.54, 19.64, 62.40, 62.46, 25 62.98, 63.04, 116.16, 116.49, 123.51, 123.75, 124.39, 124.54, 124.71, 124.81, 125.57, 125.63, 125.72, 125.87, 126.18, 30 126.39, 127.09, 127.15, 127.32, 127.46, 127.88, 128.06,

128.17, 128.27, 128.30, 128.76, 129.33, 129.42, 129.76,  
 129.82, 130.67, 130.85, 131.03, 131.22, 131.31, 131.40,  
 132.91, 141.32, 142.96, 143.11.

(c) Compound 47a was deprotected by reacting 0.247 g in 6  
 5 mL of acetone containing 0.04 g of NaOH dissolved in 0.1 mL  
 of water. The precipitated salt was washed with acetone and  
 dried producing compound 47 as a mixture of isomers (47 E/Z);  
<sup>1</sup>H NMR (D<sub>2</sub>O) δ 6.22 (s), 6.74-8.1 (m), 8.47 (d); <sup>31</sup>P NMR (D<sub>2</sub>O)  
 δ 0.12, 0.69, 0.70.

10

17. Synthesis of Compound 48.



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(a) A solution of thioxanthone (10 g) in 60 mL of benzene  
 was treated with 5.0 g of LAH by stirring for 15 min. The  
 mixture was heated and 100 mL of ether was added carefully.  
 Reflux was continued for 90 min. The cooled mixture was  
 20 neutralized with water. The solids were filtered off and the  
 filtrate evaporated to dryness. Pure thioxanthene (9.1 g, 98  
 %) was isolated by chromatography using 20 % ethyl acetate  
 /hexane; <sup>1</sup>H NMR (CDCl<sub>3</sub>) δ 3.82 (s, 3H), 7.21 (m, 4H), 7.33 (m,  
 2H), 7.46 (m, 2H).

25

(b) Thioxanthene, 9.1 g, was dissolved in 100 mL of dry  
 THF. The solution was cooled in an ice bath and n-BuLi (24 mL  
 of 2.5 M solution) was added dropwise. The red solution was  
 stirred at room temperature for one hour. Powdered CO<sub>2</sub> was  
 added (ca. 150 g) causing formation of a white precipitate.  
 30 After stirring an additional hour the mixture was evaporated  
 and the residue dissolved in water. The aqueous solution was

extracted with  $\text{CH}_2\text{Cl}_2$ , and neutralized with HCl. The precipitated product was dissolved in ether, dried and evaporated producing thioxanthene-9-carboxylic acid as a white solid (8.8 g):  $^1\text{H}$  NMR ( $\text{DMSO-d}_6$ )  $\delta$  5.25 (s, 1H), 7.30 (m, 4H), 7.49  
5 (m, 4H), 12.60 (s, 1H).

(c) Thioxanthene-9-carboxylic acid (5.8 g) and thionyl chloride (30 mL) were stirred at room temperature for 1 h. The thionyl chloride was evaporated and the residue dissolved in 100 mL of  $\text{CH}_2\text{Cl}_2$ . Pyridine (4 mL) and thiophenol (4 g) were  
10 added and the reaction mixture stirred at room temperature for 5 h. The mixture was evaporated and the residue washed with water followed by ether. The thioester was purified by chromatography using 20 % ethyl acetate/hexane yielding 6.3 g of pure phenyl thioxanthene-9-thiocarboxylate:  $^1\text{H}$  NMR ( $\text{CDCl}_3$ )  
15  $\delta$  5.16 (s, 1H), 7.32 (m, 9H), 7.50 (m, 4H);  $^{13}\text{C}$  NMR ( $\text{CDCl}_3$ )  $\delta$  63.0, 126.9, 127.3, 128.1, 128.4, 129.2, 129.4, 130.9, 132.4,  
133.7, 134.5, 196.5.

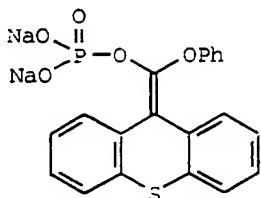
(d) The thioester (4.6 g) was deprotonated with 1.5 eq. Of LDA in 40 mL of dry THF at -78 °C for 30 min. A solution of  $\text{POCl}_3$  (3.2 g) and pyridine (1.66 g) in 10 mL of dry THF was added dropwise to the reaction which was allowed to warm to room temperature. After stirring at room temperature for 45 min, a solution of cyanoethanol (5.68 g) and pyridine (6.3 g) was added and stirring continued over night. The mixture was  
25 filtered and the filtrate concentrated to a thick residue which was chromatographed using 70 % ethyl acetate/hexane. The enol bis(cyanoethyl)phosphate (48a) was obtained as a foam (3.1 g);  $^1\text{H}$  NMR ( $\text{CDCl}_3$ )  $\delta$  2.52 (m, 4H), 3.94 (m, 4H), 7.20-7.48 (m, 10H), 7.55 (dd, 1H), 7.74 (dd, 1H), 7.85 (dd,  
30 1H);  $^{13}\text{C}$  NMR ( $\text{CDCl}_3$ )  $\delta$  19.5, 62.5, 116.6, 126.2, 126.3, 126.7, 127.0, 127.1, 128.0, 128.1, 128.2, 129.1, 129.5, 129.7,

132.5, 133.0, 133.3, 134.2, 134.3, 134.6, 137.7, 137.8;  $^{31}\text{P}$  NMR ( $\text{CDCl}_3$ )  $\delta$  -10.35 (p).

(e) Compound 48a was deprotected by reacting 1.8 g in 40 mL of argon-purged acetone containing 0.28 g of NaOH dissolved in 5.6 mL of water over night. The precipitated salt was washed with 10 % aq. acetone and dried producing compound 48 (1.57 g) as a white solid;  $^1\text{H}$  NMR ( $\text{D}_2\text{O}$ )  $\delta$  6.94-7.25 (m, 9H), 7.38 (m, 2H), 7.76 (d, 1H), 8.08 (d, 1H);  $^{31}\text{P}$  NMR ( $\text{D}_2\text{O}$ )  $\delta$  0.73 (s).

10

18. Synthesis of Compound 49.



15

Compound 49 was prepared by the sequence of reactions described in the previous example substituting phenol for thiophenol in step (c).

(a) Phenyl thioxanthene-9-thiocarboxylate:  $^1\text{H}$  NMR ( $\text{CDCl}_3$ )  $\delta$  5.26 (s, 1H), 6.94 (d, 2H), 7.15 (t, 1H), 7.24-7.34 (m, 6H), 7.51 (m, 4H).

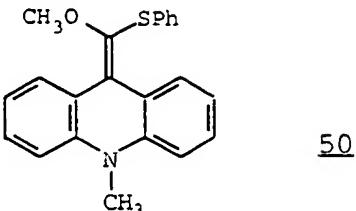
(b) 9-(Phenoxyphosphoryloxymethylidene)thioxanthene, bis(cyanoethyl)ester (49a);  $^1\text{H}$  NMR ( $\text{CDCl}_3$ )  $\delta$  2.50 (m, 4H), 3.84 (m, 2H), 4.02 (m, 2H), 7.16 (m, 5H), 7.29-7.54 (m, 7H), 7.82 (d, 1H);  $^{13}\text{C}$  NMR ( $\text{CDCl}_3$ )  $\delta$  19.5, 63.0, 124.1, 126.4, 126.5, 126.8, 127.5, 127.8, 128.0, 129.2, 130.1, 131.2, 131.4, 133.4, 134.4, 142.7, 142.9, 155.0;  $^{31}\text{P}$  NMR ( $\text{CDCl}_3$ )  $\delta$  -10.92 (p)

(c) 9-(Phenoxyphosphoryloxymethylidene)thioxanthene, disodium salt (49);  $^1\text{H}$  NMR ( $\text{D}_2\text{O}$ )  $\delta$  6.92 (t, 1H) 7.04 (t, 2H), 7.07-7.34 (m, 6H), 7.38 (t, 1H), 7.45 (d, 1H), 7.71 (d, 1H),

8.05 (d, 1H);  $^{31}\text{P}$  NMR ( $\text{D}_2\text{O}$ )  $\delta$  0.22 (s).

19. Synthesis of Compound 50.

5



Phenyl 10-methylacridan-9-thiocarboxylate, 1.0 g was converted to the enolate with LDA in 60 mL of dry THF at -70 °C.

10 After maintaining the temperature at -70 °C for 1 h, 0.76 g of methyl triflate was added and the reaction mixture was allowed to warm to room temperature. The mixture was allowed to stand for 4 days.  $\text{CH}_2\text{Cl}_2$  (150 mL) was added, the solution was extracted with water and dried on  $\text{Na}_2\text{SO}_4$ . The crude product was purified by prep. TLC with a 70/30 hexane: $\text{CH}_2\text{Cl}_2$  eluent.  $^1\text{H}$  NMR ( $\text{CDCl}_3$ )  $\delta$  3.53 (s, 3H), 3.56 (s, 3H), 6.93-7.45 (m, 11H), 7.71 (d, 1H), 7.93 (d, 1H).

20. Chemiluminescent Detection of HRP with Acridan Phosphate

20 5. Reagent compositions comprising 0.055 M tris buffer, pH 8.6, 0.25 mM urea peroxide, 0.05 mM p-phenylenphenol, 0.5 mM EDTA, 0.0125% Tween 20 and  $3.3 \times 10^{-4}$  M acridan 5 were tested for production of chemiluminescence by reacting triplicate 100  $\mu\text{L}$  aliquots with 10  $\mu\text{L}$  of solutions of HRP in water containing between  $1.4 \times 10^{-15}$  and  $1.4 \times 10^{-19}$  moles of enzyme. Light production ensued upon mixing and was measured at 5, 10 and 15 min. The relation between chemiluminescence intensity at 15 min and amount of enzyme is depicted in Figure 1.

30 21. Chemiluminescent Detection of HRP with Acridan Phosphate

13. Reagent compositions comprising 0.055 M tris buffer, pH

8.6, 0.25 mM urea peroxide, 0.05 mM p-phenyl-phenol, 0.5 mM EDTA, 0.0125% Tween 20 and  $3.3 \times 10^{-4}$  M acridan 13 were tested for production of chemiluminescence by reacting triplicate 100  $\mu$ L aliquots with 10  $\mu$ L of solutions of HRP in water containing between  $1.4 \times 10^{-15}$  and  $1.4 \times 10^{-19}$  moles of enzyme. Light production ensued upon mixing and was measured at 15 min. The relation between chemiluminescence intensity and amount of enzyme is depicted in Figure 2.

10 22. Chemiluminescent Detection with Acridan Phosphates 1-4 and 6-12 and 14. In the manner of Example 21, compositions containing each of compounds 1-4 and 6-12 and 14 were reacted with HRP at 25 °C. Each produced easily measurable chemiluminescence discernable above the background measured in the 15 absence of HRP.

20 23. Kinetic Profile of Chemiluminescence Intensity. The chemiluminescence profile of acridan phosphate 5 reacted with HRP is depicted in Figure 3. Reaction of 100  $\mu$ L of the reagent composition of Example 20 with  $1.4 \times 10^{-15}$  mol of HRP at 25 °C caused an instant rise in light emission which achieved maximum intensity in ca. 5 min.

25 24. Chemiluminescent Detection of HRP with Acridan Diethyl Phosphate 37. Reagent compositions comprising 0.01 M tris buffer, pH 8.0, 0.5 mM urea peroxide, 0.1 mM p-phenyl-phenol, 1 mM EDTA, 0.025% Tween 20 and  $5 \times 10^{-5}$  M acridan 37 were tested for production of chemiluminescence by reacting triplicate 100  $\mu$ L aliquots with 10  $\mu$ L of HRP in the range  $1.4 \times 10^{-14}$  to  $1.4 \times 10^{-19}$  moles. Light production ensued upon mixing and was measured at 2 min. The relation between chemilumines-

cence intensity and amount of enzyme is depicted in Figure 4.

25. Chemiluminescent Detection of HRP with Acridan Diethyl

Phosphate 38. A reagent composition (40  $\mu$ L) comprising 0.01 M tris buffer, pH 8.0, 0.5 mM urea peroxide, 0.1 mM p-phenylphenol, 1 mM EDTA, 0.025% Tween 20 and  $5 \times 10^{-5}$  M acridan 38 was reacted with 1  $\mu$ L of a solution containing  $1.4 \times 10^{-15}$  moles of HRP. Light production ensued upon mixing and reached maximum intensity in 1 min. The chemiluminescence time profile is depicted in Figure 5.

26. Chemiluminescent Detection of HRP with Acridan Acetate

39. Reagent compositions comprising 0.01 M tris buffer, pH 8.0, 0.5 mM urea peroxide, 0.1 mM p-phenylphenol, 1 mM EDTA, 0.025% Tween 20 and  $5 \times 10^{-5}$  M acridan 39 were tested for production of chemiluminescence by reacting triplicate 100  $\mu$ L aliquots with 10  $\mu$ L of HRP in the range  $1.4 \times 10^{-15}$  to  $1.4 \times 10^{-20}$  moles. Light production ensued upon mixing and reached maximum intensity in 30 min. The relation between chemiluminescence intensity and amount of enzyme is depicted in Figure 6.

27. Chemiluminescent Detection of HRP with Acridan Acetate

40. A reagent composition (100  $\mu$ L) comprising 0.01 M tris buffer, pH 8.0, 0.5 mM urea peroxide, 0.1 mM p-phenyl-phenol, 1 mM EDTA, 0.025% Tween 20 and  $5 \times 10^{-5}$  M acridan 40 was reacted with 10  $\mu$ L of a solution containing  $1.4 \times 10^{-15}$  moles of HRP. Light production ensued upon mixing and reached maximum intensity in 7 min.

30

28. Chemiluminescent Detection of HRP with Acridan 50. A

reagent composition (100  $\mu$ L) comprising 0.01 M tris buffer, pH 8.0, 0.5 mM urea peroxide, 0.1 mM p-phenylphenol, 1 mM EDTA, 0.025% Tween 20 and  $5 \times 10^{-5}$  M acridan 50 was reacted with 2.5  $\mu$ L of a solution containing  $3.5 \times 10^{-16}$  moles of HRP.

5 Light production ensued upon mixing and reached maximum intensity in 7 min. The chemiluminescence time profile is depicted in Figure 7.

29. Chemiluminescent Detection of HRP with Compound 43.

10 Reagent compositions comprising 0.055 M tris buffer, pH 8.6, 0.25 mM urea peroxide, 0.05 mM p-phenylphenol, 0.5 mM EDTA, 0.0125% Tween 20, 1 mM CTAB and  $6.6 \times 10^{-4}$  M acridan 43 were tested for production of chemiluminescence by reacting triplicate 100  $\mu$ L aliquots with 10  $\mu$ L of solutions of HRP containing between  $1.4 \times 10^{-15}$  and  $1.4 \times 10^{-19}$  moles of HRP. The relation between chemiluminescence intensity at 15 min and amount of enzyme is depicted in Figure 8.

30. Chemiluminescent Detection of HRP with Compound 46 and Enhancement of Chemiluminescence with Energy Transfer Agent.

20 Reagent compositions comprising 0.055 M tris buffer, pH 8.6, 0.25 mM urea peroxide, 0.05 mM p-phenylphenol, 0.5 mM EDTA, 0.0125% Tween 20, 1 mM CTAB and  $6.6 \times 10^{-4}$  M compound 46 alone or with 50  $\mu$ M DBA were tested for production of chemiluminescence by reacting a 100  $\mu$ L aliquot with  $3.5 \times 10^{-15}$  moles of 25 HRP. The relative chemiluminescence time profiles are depicted in Figure 9 and demonstrate the enhancement of chemiluminescence by the triplet energy acceptor DBA.

31. Chemiluminescent Detection of HRP with Compound 48.

30 Reagent compositions comprising 0.055 M tris buffer, pH 8.6, 0.25 mM urea peroxide, 0.05 mM p-phenylphenol, 0.5 mM EDTA,

0.0125% Tween 20 and  $3.3 \times 10^{-4}$  M compound 48 were tested for production of chemiluminescence by reacting a 100  $\mu\text{L}$  aliquot with  $3.5 \times 10^{-15}$  moles of HRP. The chemiluminescence time profile is depicted in Figure 10.

5

32. Chemiluminescent Detection of HRP with Compound 49.

Reagent compositions comprising 0.055 M tris buffer, pH 8.6, 0.25 mM urea peroxide, 0.05 mM p-phenylphenol, 0.5 mM EDTA, 0.0125% Tween 20 and  $3.3 \times 10^{-4}$  M compound 49 were tested for production of chemiluminescence by reacting a 100  $\mu\text{L}$  aliquot with  $3.3 \times 10^{-15}$  moles of HRP. The chemiluminescence time profile is depicted in Figure 11.

10

33. Western Blot Assay using PVDF Membrane. Compositions of the present invention were used to detect and quantify a protein,  $\beta$ -galactosidase ( $\beta$ -gal) in a Western blot with an HRP-labeled antibody on a polyvinylidene difluoride (PVDF) membrane. Dilutions of  $\beta$ -gal containing 5000, 1000, 180, 30 and 5 pg, respectively, of protein were electrophoresed and transferred to PVDF membranes (Millipore, Bedford, MA). The membranes were blocked with 1% non-fat milk in T-TBS (0.05% Tween 20 in TBS; TBS is 50 mmol/L Tris-HCl, pH 7.4, 0.15 mol/L NaCl) and then reacted sequentially with a 1:1500 dilution of mouse anti- $\beta$ -gal (Boehringer-Mannheim, Indianapolis) and 1:600 dilution of sheep anti-mouse-HRP conjugate (Boehringer-Mannheim). The membranes were washed in T-TBS and soaked for 3 min with a reagent comprising 0.055 M tris buffer, pH 8.6 containing 0.66 mM acridan phosphate 5, 0.05 mM p-phenylphenol, 0.25 mM urea peroxide, 0.5 mM EDTA, 0.0125% Tween 20. The membranes were placed between transparent plastic sheets and exposed to X-ray film. Figure 12

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20

25

30

demonstrates the detection of  $\beta$ -gal after 14 min with a 30 s exposure. The light produced led to intense emission which could be imaged for several hours.

5     34. Western Blot using Nitrocellulose Membrane. A Western blot assay according to the procedure in the previous example was performed using nitrocellulose membrane (Schleicher & Schuell, Keene, NH) as the solid phase.  $\beta$ -Gal standards in the range of 5000 - 5 pg were used. The detection reagent of  
10    the previous example permitted detection to be performed over several hours. Figure 13 demonstrates the detection of  $\beta$ -gal after 10 min with a 5 min exposure.

15    35. Western Blot using Other Chemiluminescent Reagents of the Present Invention. Similar Western blot assays of  $\beta$ -galactosidase on both PVDF and nitrocellulose membranes using detection reagents containing in place of compound 5, each of compounds 1, 12 and 13 with qualitatively the same result.

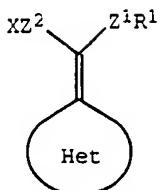
20    35. Southern Blot using a Chemiluminescent Reagents of the Present Invention. A Southern blot assay can be performed according to the methods described in applicant's U.S. Patent 5,593,845 by substituting for the detection reagent described therein a reagent composition according to Example 20 or 33 of the present invention.

25

The foregoing description and examples are illustrative only and not to be considered as restrictive. It is recognized that modifications of the specific compounds and methods not specifically disclosed can be made without departing  
30    from the spirit and scope of the present invention. The scope of the invention is limited only by the appended claims.

## WHAT IS CLAIMED IS:

1. A compound of formula II:

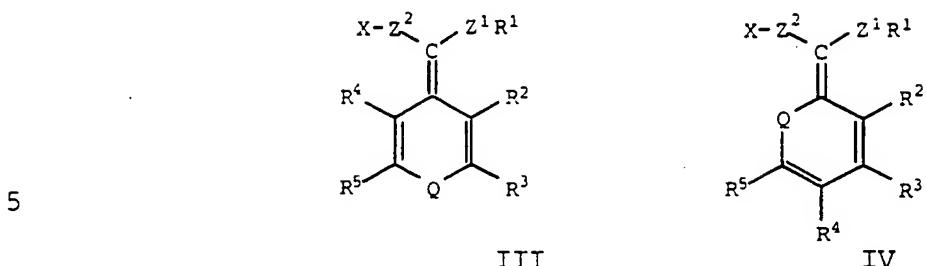


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II

wherein Het is a heterocyclic ring system comprising at least one five or six-membered ring which comprises at least one heteroatom selected from the group consisting of N, O and S atoms, X is selected from substituted or unsubstituted alkyl, substituted or unsubstituted aryl, substituted or unsubstituted aralkyl groups of 1-20 carbon atoms, substituted or unsubstituted alkyl or aryl carboxyl groups having from 1-20 carbon atoms, tri(C<sub>1</sub>-C<sub>8</sub> alkyl)silyl groups, 15 an SO<sub>3</sub><sup>-</sup> group and glycosyl groups, Z<sup>1</sup> and Z<sup>2</sup> are independently selected from O and S atoms and R<sup>1</sup> is an organic group containing from 1 to 50 non-hydrogen atoms selected from C, N, O, S, P, Si and halogen atoms.

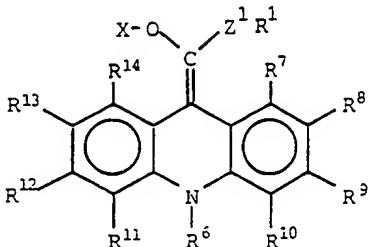
## 2. A compound of the formula III or IV



wherein X is selected from substituted or unsubstituted alkyl, substituted or unsubstituted aryl, substituted or unsubstituted aralkyl groups of 1-20 carbon atoms,  
 10 substituted or unsubstituted alkyl or aryl carboxyl groups having from 1-20 carbon atoms, tri(C<sub>1</sub>-C<sub>8</sub> alkyl)silyl groups, a SO<sub>3</sub><sup>-</sup> group and glycosyl groups, Q is selected from NR<sup>6</sup>, O and S atoms, each of R<sup>2</sup> to R<sup>5</sup> is a substituent containing from 1 to 50 atoms selected from C, H, N, O, S, P, Si and halogen atoms  
 15 which permits the chemiluminescence to be produced and wherein pairs of adjacent groups can be joined together to form a carbocyclic or heterocyclic ring system comprising at least one 5 or 6-membered ring and wherein R<sup>6</sup> is an organic group containing from 1 to 50 non-hydrogen atoms  
 20 selected from C, N, O, S, P, Si and halogen atoms, Z<sup>1</sup> and Z<sup>2</sup> are independently selected from O and S atoms and R<sup>1</sup> is an organic group containing from 1 to 50 non-hydrogen atoms selected from C, N, O, S, P, Si and halogen atoms.

3. The compound of Claim 2 wherein, in the compound of formula III Z<sup>2</sup> is oxygen, Q is the NR<sup>6</sup> group and having the formula:

5



wherein each of R<sub>7</sub> to R<sub>14</sub> is independently a substituent which can contain from 1 to 50 atoms selected from C, H, N, O, S, P, Si and halogen atoms and which permits the chemiluminescence to be produced.

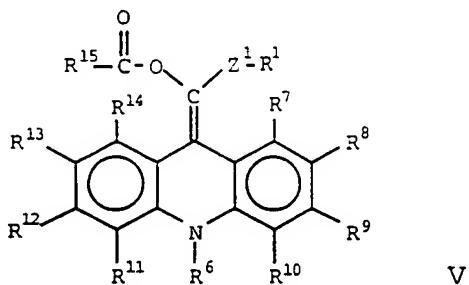
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4. The compound of Claim 3 wherein at least one of R<sub>7</sub> to R<sub>14</sub> is a halogen or an alkoxy group and the remaining of R<sub>7</sub> to R<sub>14</sub> are hydrogen.

5. The compound of Claim 4 wherein R<sup>6</sup> is selected from C<sub>1</sub> - C<sub>4</sub> substituted or unsubstituted alkyl, substituted or unsubstituted benzyl, alkoxyalkyl and carboxyalkyl groups.

6. The compound of Claim 3 having the formula:

5



V

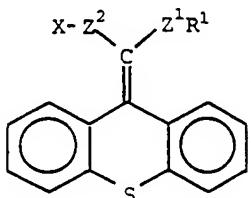
wherein R<sup>15</sup> is a substituted or unsubstituted alkyl or aryl group having from 1-20 carbon atoms.

7. The compound of Claim 6 wherein each of R<sup>7</sup> to R<sup>14</sup> is a

hydrogen atom and R<sup>15</sup> is methyl .

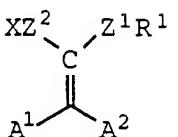
8. The compound of Claim 2 wherein, in the compound of formula III, Q is the S atom, and having the formula:

5



wherein X is selected from substituted or unsubstituted alkyl, substituted or unsubstituted aryl, substituted or unsubstituted aralkyl groups of 1-20 carbon atoms, substituted or unsubstituted alkyl or aryl carboxyl groups having from 1-20 carbon atoms, tri(C<sub>1</sub>-C<sub>8</sub> alkyl)silyl groups, an SO<sub>3</sub><sup>-</sup> group and glycosyl groups, Z<sup>1</sup> and Z<sup>2</sup> are independently selected from O and S atoms and R<sup>1</sup> is an organic group containing from 1 to 50 non-hydrogen atoms selected from C, N, O, S, P, Si and halogen atoms.

9. A compound of the formula I:



I

5 wherein X is selected from substituted or unsubstituted alkyl, substituted or unsubstituted aryl, substituted or unsubstituted aralkyl groups of 1-20 carbon atoms, substituted or unsubstituted alkyl or aryl carboxyl groups having from 1-20 carbon atoms, tri(C<sub>1</sub>-C<sub>8</sub> alkyl)silyl groups,

10 an SO<sub>3</sub><sup>-</sup> group, glycosyl groups and phosphoryl groups of the formula -PO(OR')(OR'') wherein R' and R'' are independently selected from substituted or unsubstituted alkyl, substituted or unsubstituted aryl and substituted or unsubstituted aralkyl groups of 1-20 carbon atoms, trialkylsilyl groups,

15 alkali metal cations and alkaline earth cations, Z<sup>1</sup> and Z<sup>2</sup> are independently selected from O and S atoms, R<sup>1</sup> is an organic group having from 1 to 50 non-hydrogen atoms selected from C, N, O, S, P, Si and halogen atoms to produce the chemiluminescence and an electronic excited state compound

20 having the formula A<sup>1</sup>A<sup>2</sup>C=O wherein one of A<sup>1</sup> and A<sup>2</sup> is an aryl group substituted with at least one group selected from amino, alkylamino, dialkylamino and OY' where Y' is hydrogen or an alkali metal ion, and the other of A<sup>1</sup> and A<sup>2</sup> is selected from alkyl, substituted alkyl, aryl, substituted aryl, aralkyl, substituted aralkyl, heteroaryl, substituted heteroaryl, alkenyl, alkynyl, alkoxy, aryloxy, alkylamino, arylamino, alkylthio and arylthio.

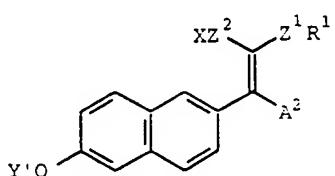
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10. The compound of Claim 9 wherein the aryl group comprises 1-4 fused carbocyclic or heterocyclic 5 or 6-membered rings.

11. The compound of Claim 9 wherein the aryl group is selected from phenyl, naphthyl, anthryl and pyrenyl groups.

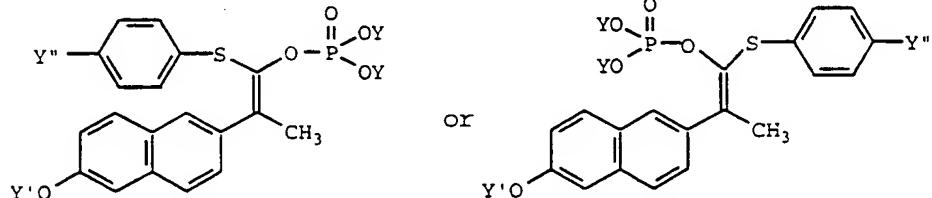
12. The compound of Claim 9 wherein A<sup>1</sup> is a naphthyl group and having the formula:

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13. The compound of Claim 12 having the formula:

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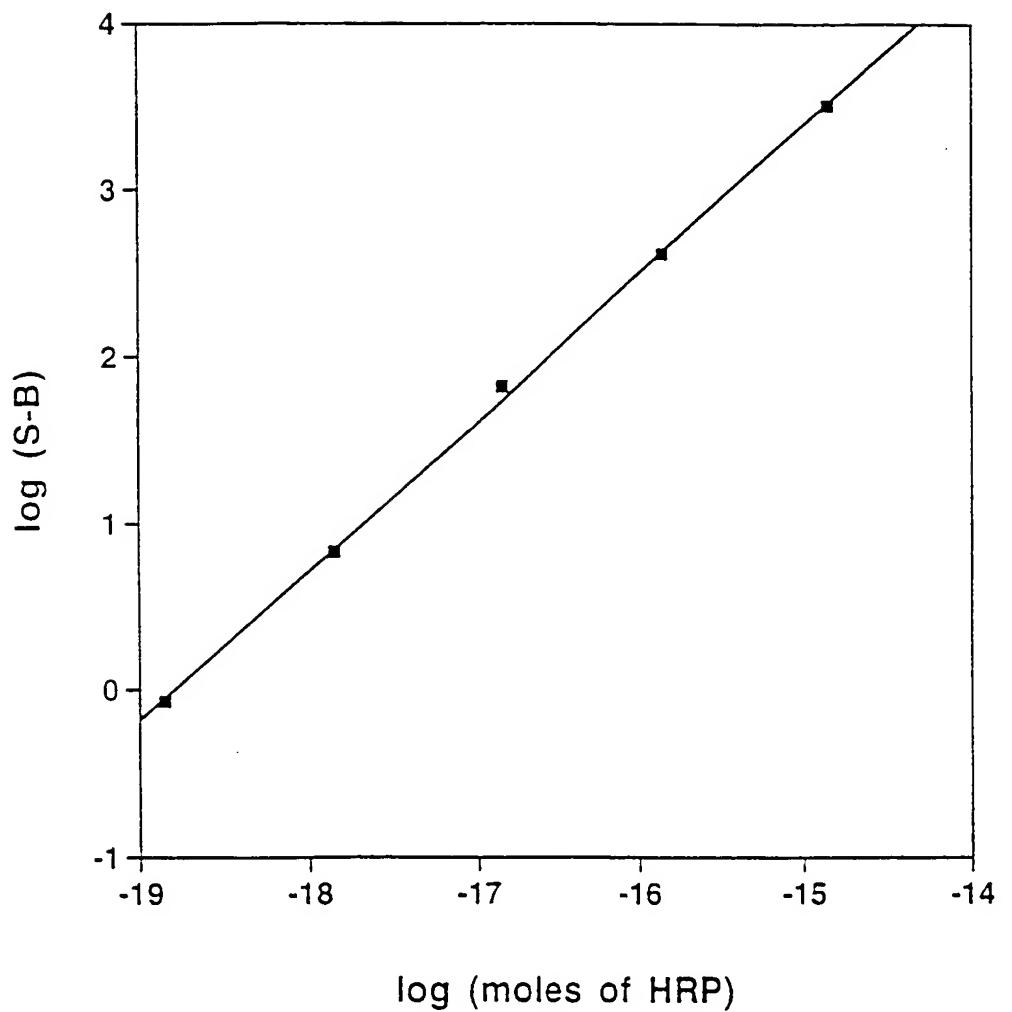
wherein Y is selected from hydrogen, an alkali metal ion or a substituted or unsubstituted alkyl, substituted or unsubstituted aryl, substituted or unsubstituted aralkyl and trialkylsilyl groups and Y" is selected from hydrogen and halogen.  
10

14. The compound of Claim 12 wherein Y is a sodium ion, Y' is hydrogen or a sodium ion and Y" is hydrogen or chlorine.

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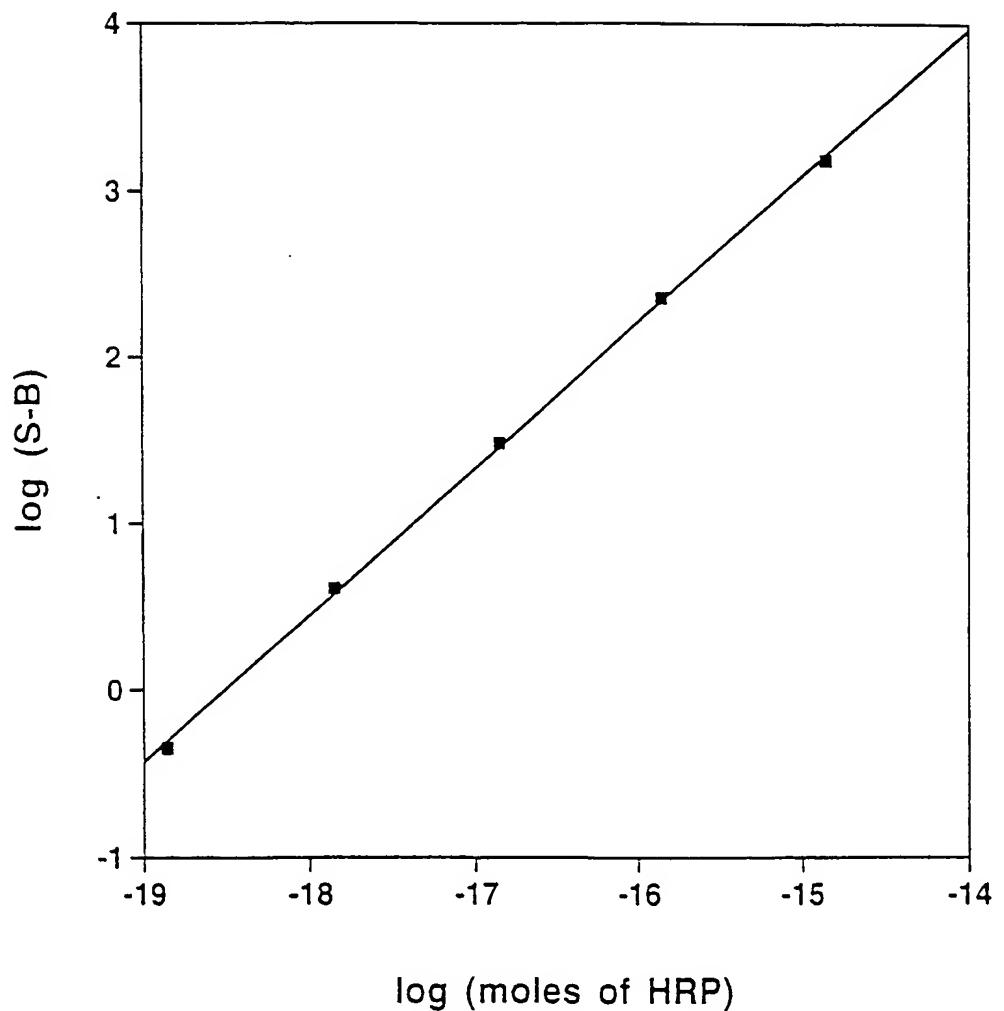
Fig. 1



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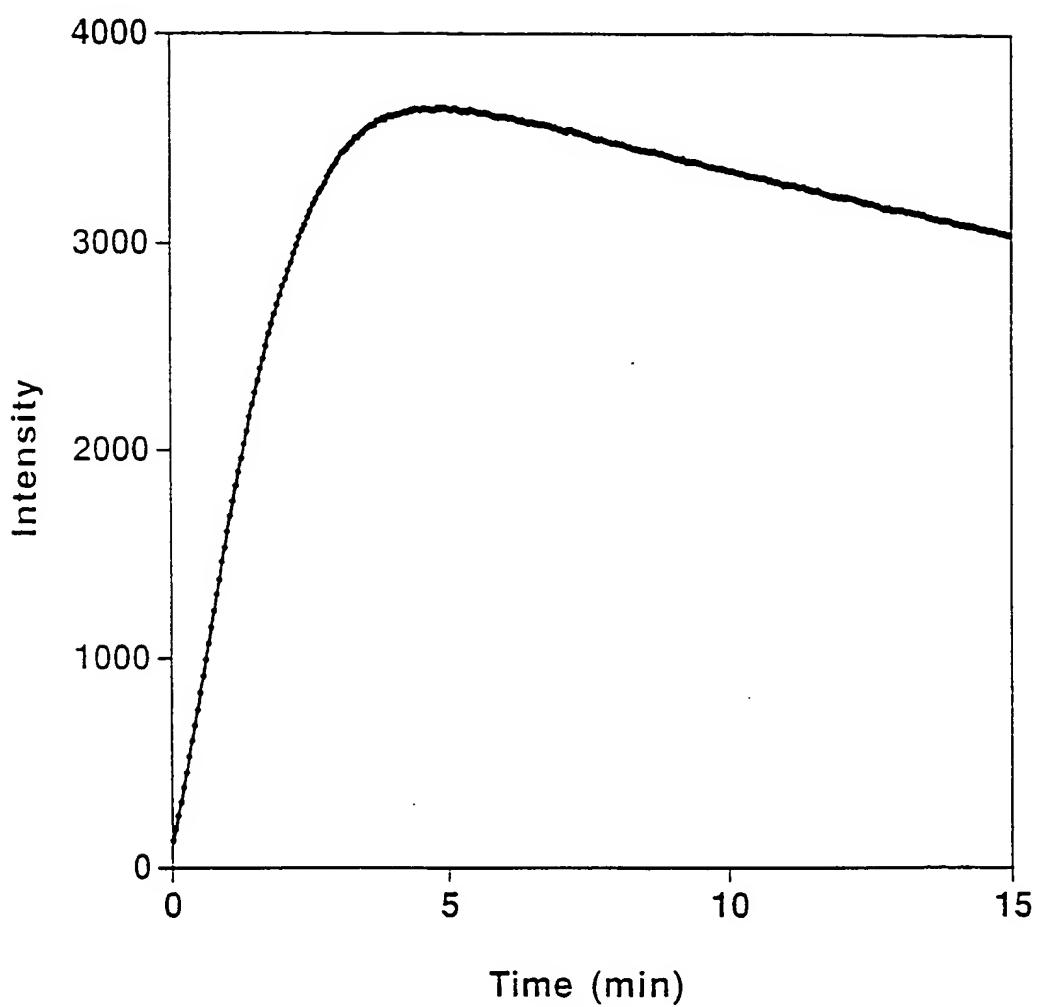
Fig. 2



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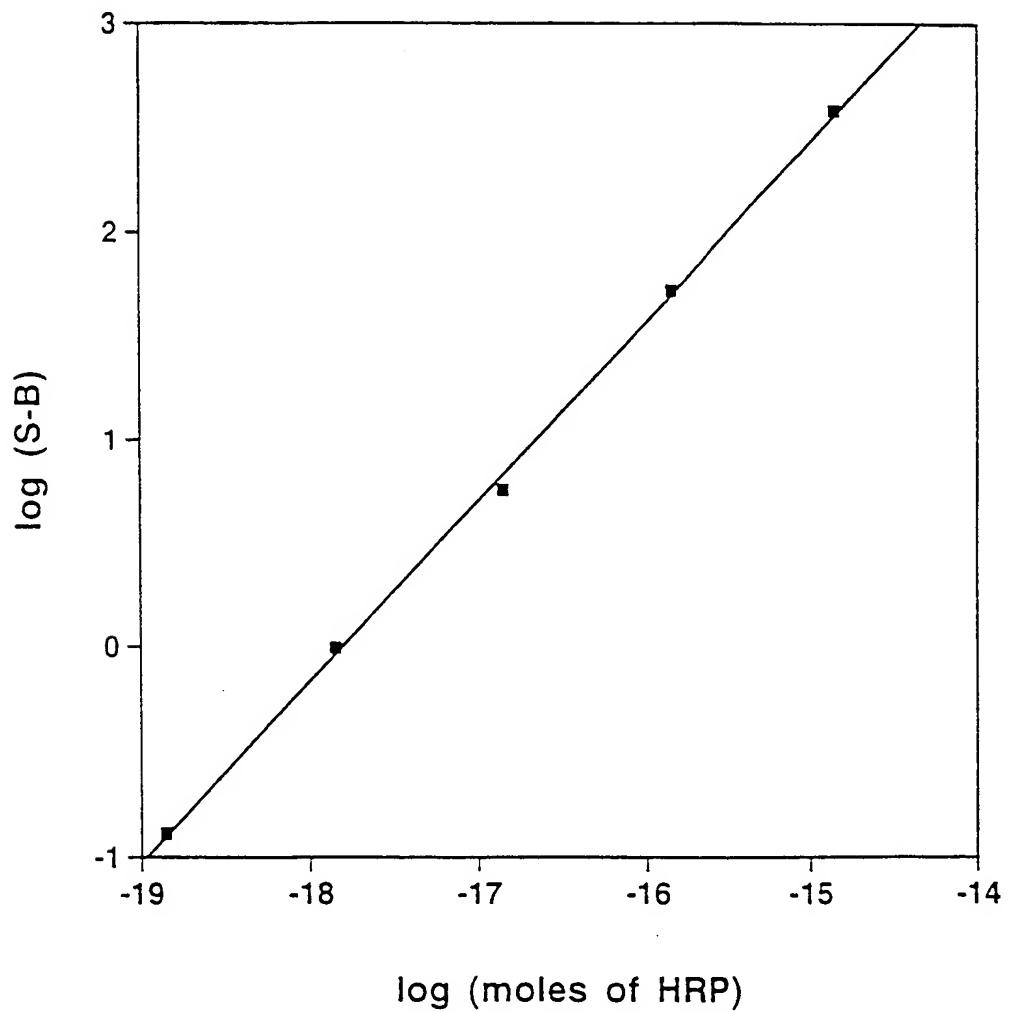
Fig. 3



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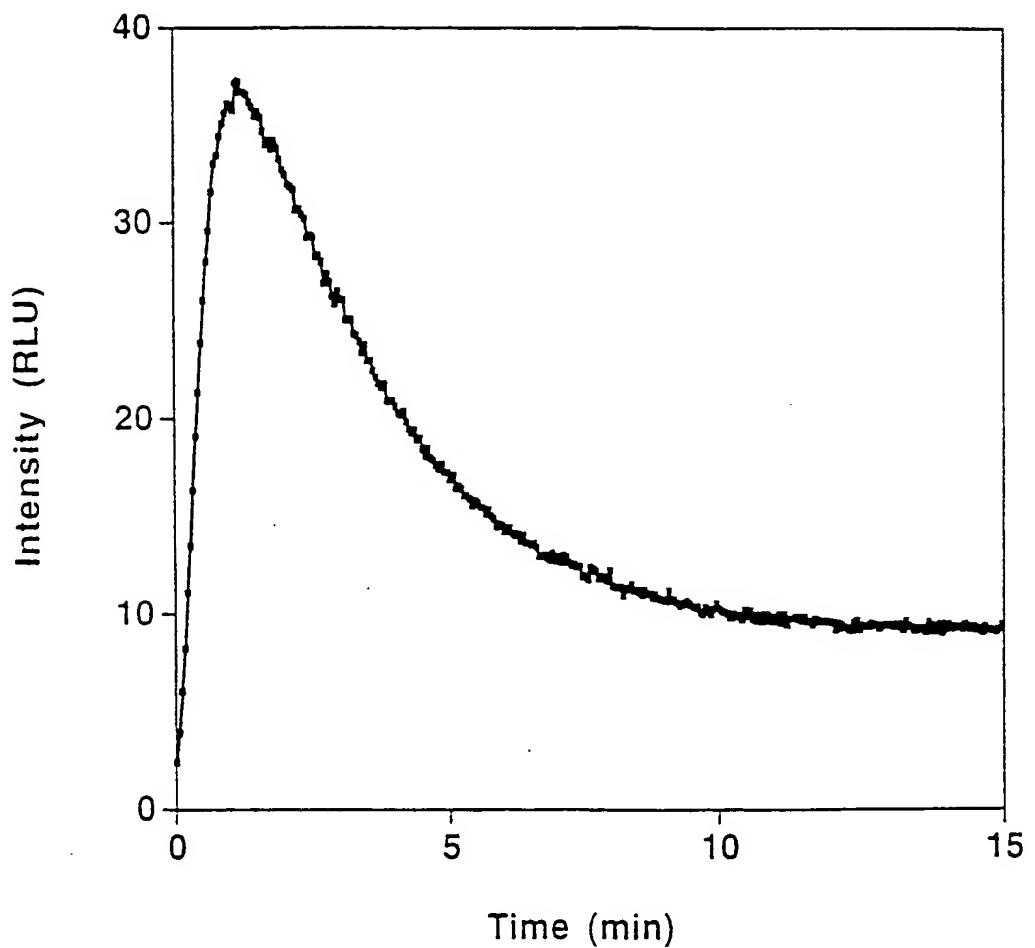
Fig. 4



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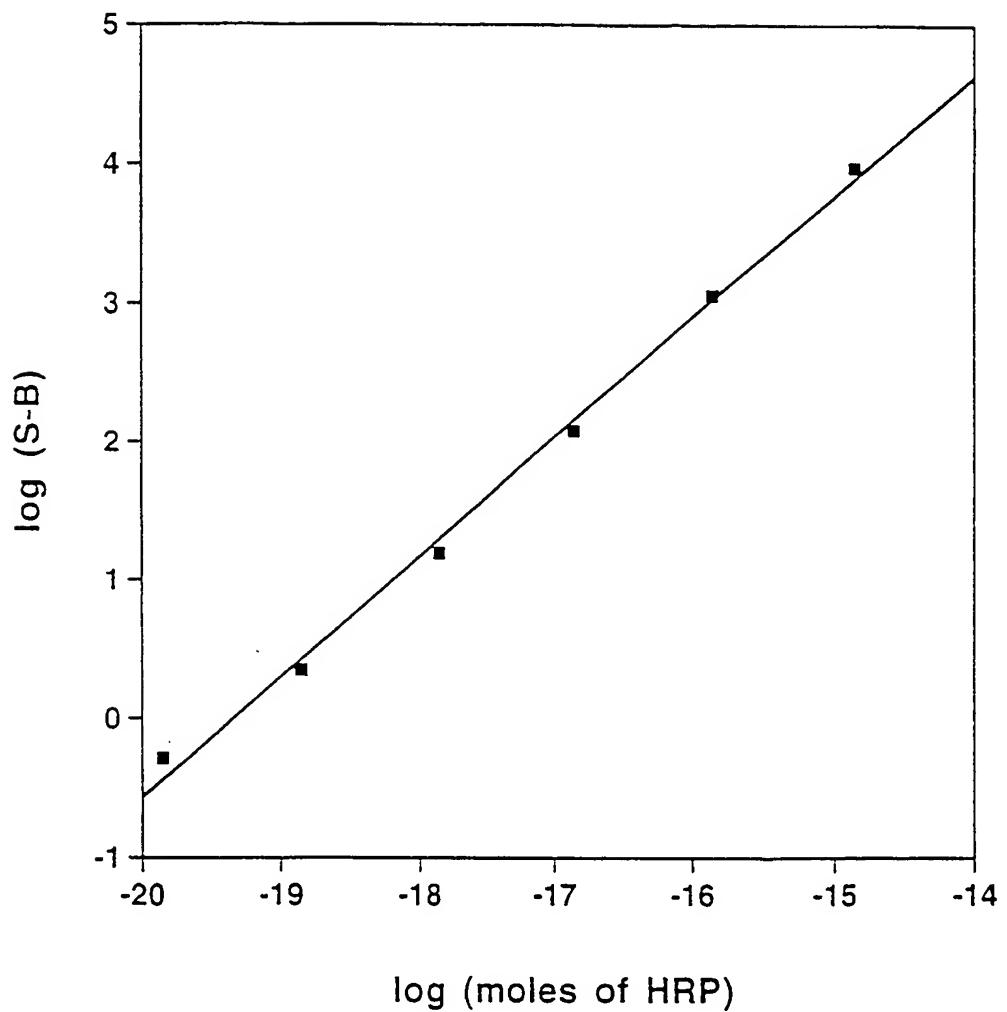
Fig. 5



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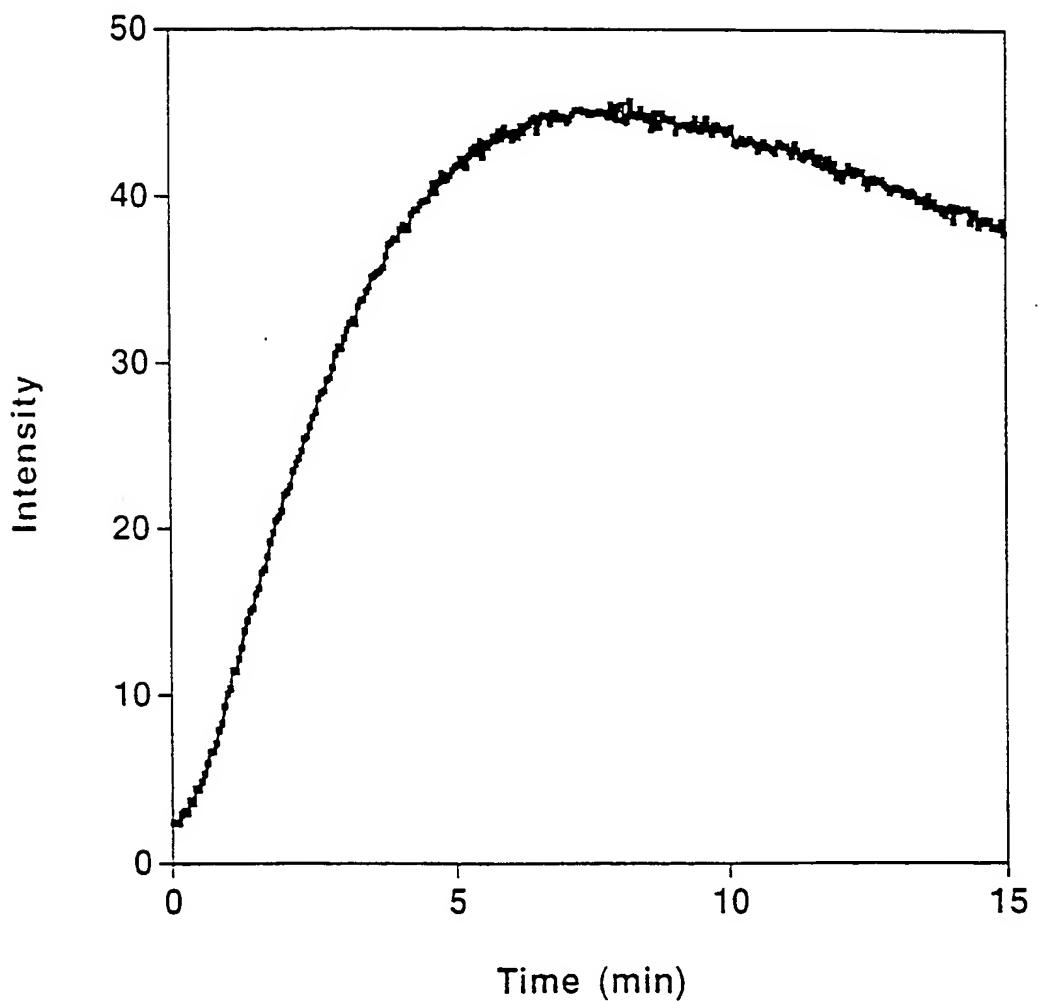
Fig. 6



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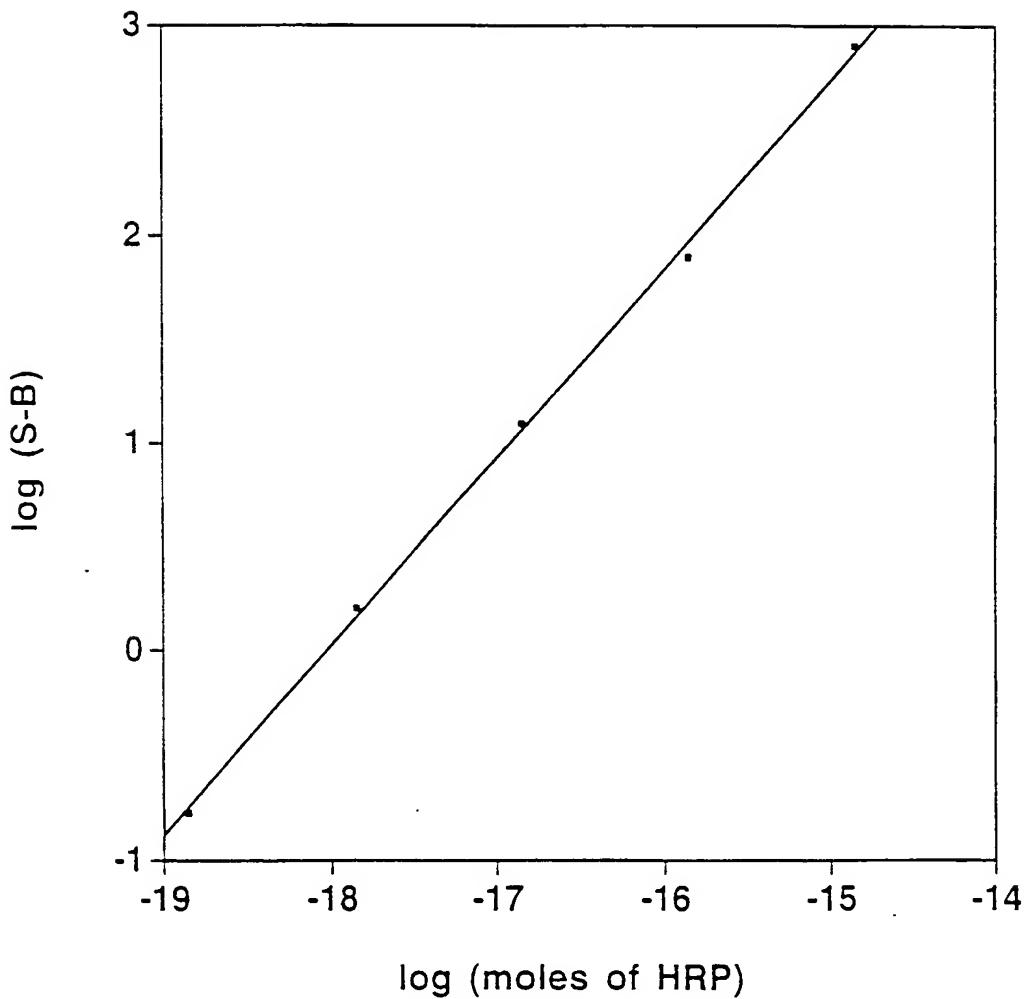
Fig. 7



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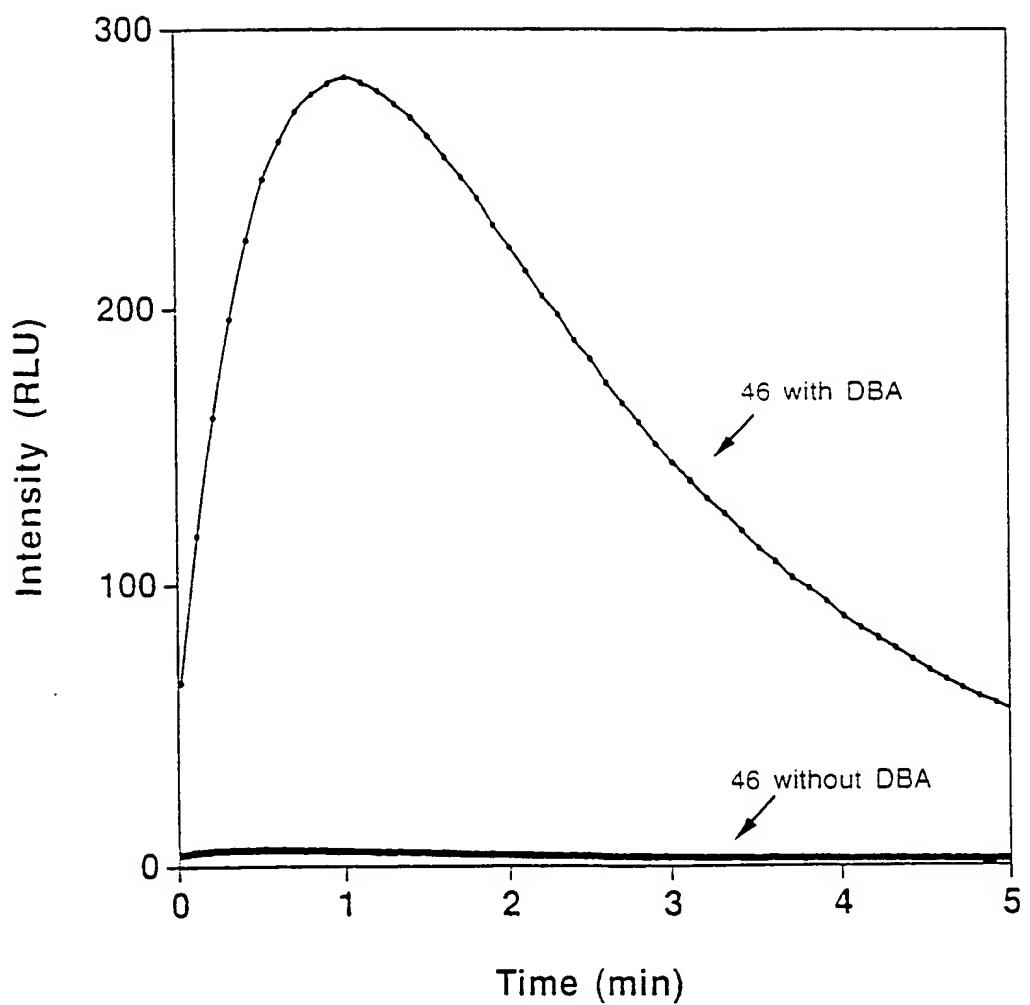
Fig. 8



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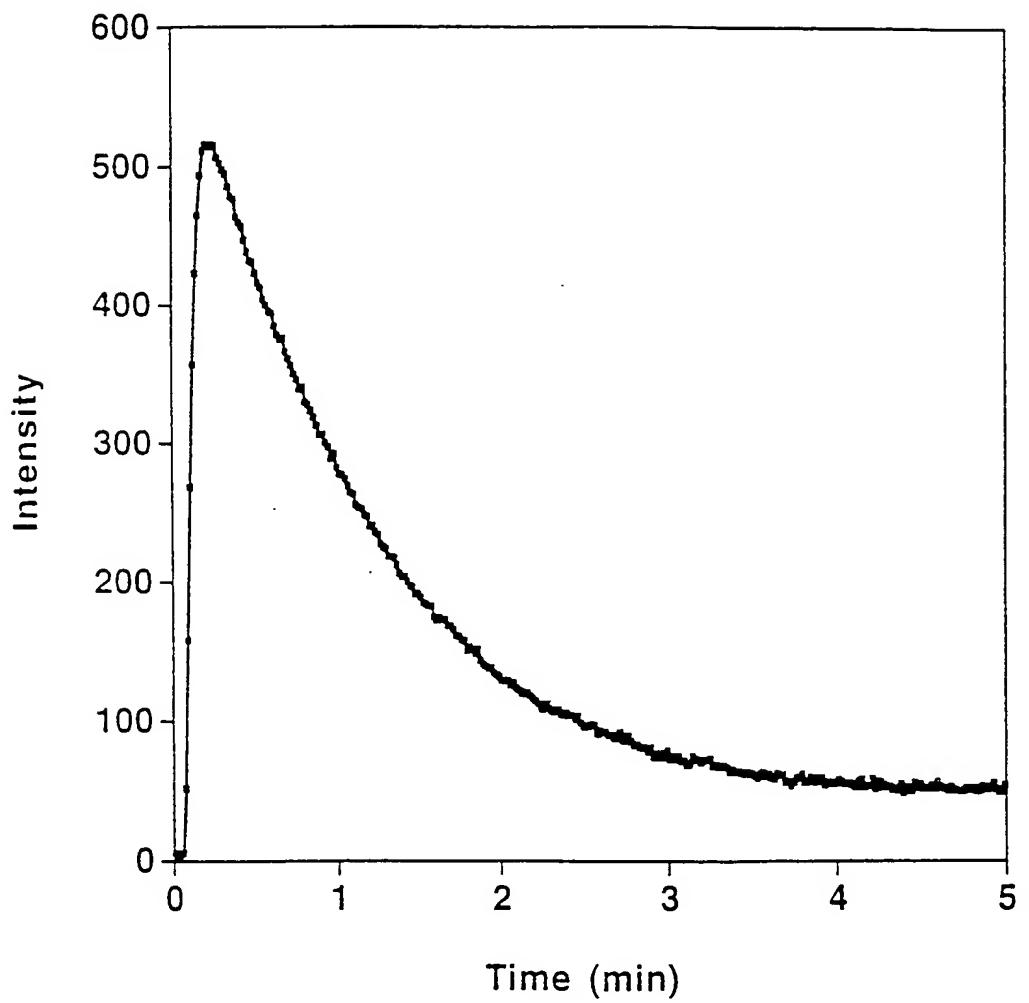
Fig. 9



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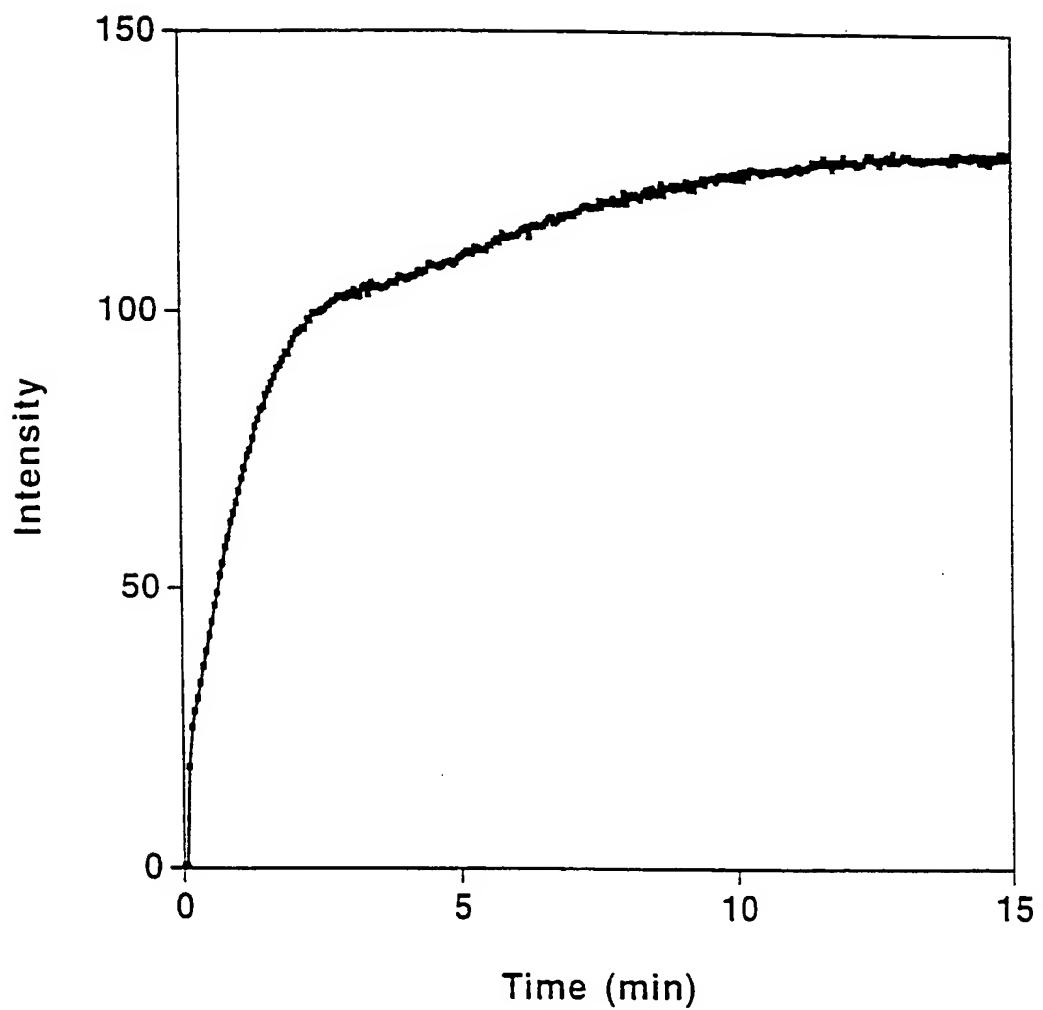
Fig. 10



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Fig. 11



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FIG. 12

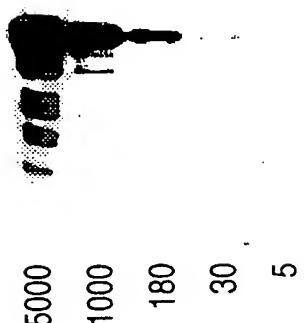
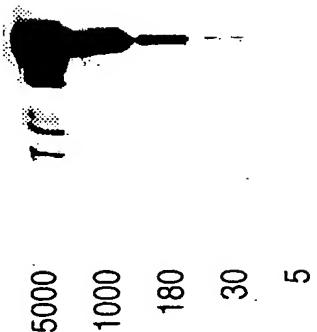


FIG. 13



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## INTERNATIONAL SEARCH REPORT

International application No.

PCT/US98/15734

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :Please See Extra Sheet.

US CL :Please See Extra Sheet.

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 556/404, 405; 558/70; 562/20; 546/14, 102, 108, 101; 549/4, 5, 26, 215

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5,324,835 A (YAMAGUCHI) 28 June 1994, see entire document.	1-14
A	US, 5,171,668 A (SUGIYAMA) 15 December 1992, see entire document.	1-14
A	US 5,491,072 A (AKHAVAN-TAFTI et al.) 13 February 1996, see entire document.	1-14
A	US 5,206,149 A (OYAMA et al.) 27 April 1993, see entire document.	1-14

 Further documents are listed in the continuation of Box C.  See patent family annex.

* Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
*A* document defining the general state of the art which is not considered to be of particular relevance	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
*E* earlier document published on or after the international filing date	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
*L* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&"	document member of the same patent family
*O* document referring to an oral disclosure, use, exhibition or other means		
*P* document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search  04 DECEMBER 1998	Date of mailing of the international search report  20 JAN 1999
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230	Authorized officer <i>D. Lawrence Tor</i> PAUL F. SHAVER Telephone No. (703) 308-0196

**INTERNATIONAL SEARCH REPORT**

International application No.

PCT/US98/15734

**A. CLASSIFICATION OF SUBJECT MATTER:**

IPC (6):

C07F 7/08, 7/18, 7/02, 9/02, 9/22; C07D 219/00, 221/06, 221/12, 327/00, 335/09

**A. CLASSIFICATION OF SUBJECT MATTER:**

US CL :

556/404, 405; 558/70; 562/20; 546/14, 102, 108, 101; 549/4, 5, 26, 215